Access to Dimensional Values can be Unselective during Early Perceptual Processing

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Abstract

On each trial of the primary task for the study, a pair of small circles appeared on a computer screen. Across trials, the circles appeared in an array of positions on the screen. The participant was required on each trial to indicate whether or not the test circles were two or fewer position units apart in terms of the horizontal dimension of this array. The discrimination that the task required was easier to the extent that the vertical distance between the circles was ignored. When the task was performed under a high degree of speed stress, vertical and horizontal distance exerted equivalent effects on measures of performance. When the task was performed under a lesser degree of speed stress, horizontal distance exerted a larger effect than vertical distance. The results supported the early holistic hypothesis over the dimensional similarity hypothesis as an account of the way information from different dimensions is accessed in perceptual processing.

Humans tend to understand the world in quantitative terms. We think of a watermelon not simply as large or small but rather as having a certain particular size relative to other things that we might experience. In fact, we generally think of things as having multiple quantitative attributes. In addition to size, the watermelon will have a certain weight, age, cost, etc. Thus, human experience unfolds within a framework of perceptual dimensions. The multidimensional character of experience imposes demands on the human perception system. In particular, considerable flexibility is required. In order to completely understand a given stimulus, one must typically evaluate it on many dimensions. At the same time, situations arise in which one must evaluate the stimulus on just one of the many relevant dimensions.

The human capacity for evaluating a stimulus on a single perceptual dimension has been studied with two speeded classification tasks. In these tasks, participants are required to sort simple stimuli into categories on the basis of their values on perceptual dimensions. In the experimental condition of the *correlated-values task*, the stimuli vary on a *focal* dimension, upon which the required categorization is supposed to be based, and on another *non-focal* dimension, and the values on the two dimensions are correlated (See Figure 1). In the baseline condition, the stimuli only vary on the focal dimension. A *redundancy effect* is said to occur if responses are faster and/or more accurate in the experimental condition than in the baseline condition (Garner, 1974; Garner & Felfoldy, 1970; Melara, 1989; Melara, Marks, & Potts, 1993a; Smith & Kemler, 1978). In the experimental condition of the *orthogonal-values task*, the stimuli again vary on a focal and a non-focal dimension, but here the values on the two dimensions are uncorrelated (See Figure 2). The baseline condition is the same as for the correlated values task. An *interference effect* is said to occur if responses are slower and/or less accurate in the experimental condition than in the baseline condition (Garner, 1974; Garner & Felfoldy, 1970; Melara, 1989; Melara, Marks, & Potts, 1993a; Smith & Kemler, 1978). On the basis of work with the correlated-values and orthogonal-values tasks (as well as other tasks) two kinds of perceptual dimensions have been distinguished. Interacting dimensions are associated with redundancy effects in the correlated-values task and interference effects in the orthogonal-values task. Non-interacting dimensions are associated with neither redundancy nor interference effects.

Insert Figure 1 about here

Insert Figure 2 about here

Psychologists have been particularly intrigued by the failures of selective evaluation that occur with interacting dimensions. Until recently, the prevailing view of such failures has been the *early holistic hypothesis*. This hypothesis claims that, when a stimulus has values on two interacting dimensions, access to these values is often completely un-selective during the early stages of perceptual processing. Only during later stages of processing is access to this dimensional information selective. As a consequence, pairs of interacting dimensions are often *perceptually inseparable* during the early stages of processing. In other words, the perceptual effect of a stimulus on one dimension is often influenced by the value of the stimulus on the other dimension. It is for this reason that we observe redundancy effects in the correlated-values task and interference effects in the orthogonal-values task (Grau & Kemler Nelson, 1988; Lockhead, 1972; Lockhead, 1979; Kemler Nelson, 1993).

Recently, the early holistic hypothesis has come under attack. Exception has been taken, in particular, to the view that access to information from interacting dimensions is completely un-selective during early perceptual processing. According to the *dimensional similarity hypothesis,* stimuli undergo two sorts of processing when they are perceived. In attribute-level processing, which occurs for all stimuli, information is considered that independently locates a given stimulus on all of the dimensions along which it varies. In stimulus-level processing, which occurs for stimuli that vary on pairs of interacting dimensions, information is jointly considered that locates each stimulus on both of the dimensions along which it varies. Because attribute-level processing occurs for all stimuli, including stimuli that vary along interacting dimensions, it is never the case that access to information from interacting dimensions is completely un-selective, even during the early stages of processing. As a consequence of stimulus-level processing, however, access may be somewhat un-selective (Melara, 1992; Melara & Marks, 1990a).

As a key part of their challenge to the early holistic hypothesis, dimensional similarity proponents have criticized the interpretation of redundancy and interference effects. In questioning the interpretation of redundancy effects, dimensional similarity proponents have appealed to a distinction between perceptual and decision processes (Maddox, 1992; Maddox & Ashby, 1996; Maddox, 2001). Early holistic proponents are interested in perceptual processes. They wish to interpret redundancy effects as evidence that the focal and non-focal dimensions are perceptually inseparable – that the perceptual effect of a stimulus on the focal dimension is influenced by the value of the stimulus on the non-focal dimension. Dimensional similarity proponents have pointed out, however, that this does not necessarily follow. The influence of non-focal information might be induced by decision factors. The correlated values task can be performed in two ways – on the basis of two decision rules. 1) In the case of the one-dimensional rule, response decisions are characterized by *decisional separability* - they are based solely on information from the focal dimension (the decision boundary is shown as the dotted line in Figure 1) (Maddox, 1992). 2) In the case of the two-dimensional rule, response decisions are not characterized by decisional separability – they are based on information from both dimensions of the stimulus set (the decision boundary is shown as the dashed line in Figure 1). The required discrimination can be performed more easily under the two- than the one-dimensional decision rule. To see this, note that in Figure 1 the points corresponding to the stimuli are farther from the two- than the one-dimensional decision boundary. Thus, it makes sense to perform the task on the basis of the two- rather than the one-dimensional decision rule. Therefore, it might be the case that the focal and non-focal dimensions are perceptually separable, but that non-focal information is used in performing the task because the task is thereby performed more easily. For this reason, redundancy effects are not good evidence of early holistic processing (Melara, Marks, & Potts,1993b).

In questioning the interpretation of interference effects, dimensional similarity proponents have focused on a crucial difference between the correlated- and orthogonal-values tasks. Performance in the correlated-values task improves when the stimuli vary on the non-focal dimension. By implication, non-focal information is used (along with focal information) in performing the task. In contrast, performance on the orthogonal-values task gets worse when the stimuli vary on the non-focal dimension. By implication, non-focal information is not used in performing the task. Rather, such information impedes performance in some way. But non-focal information might impede performance through many different mechanisms. Thus, interference effects constitute somewhat non-specific evidence of the role of non-focal information in the orthogonal-values task. To drive their point home, dimensional similarity proponents have called attention to the fact that interference effects occur even when the dimensions of the stimulus set pertain to different modalities. Because it is unlikely that access to dimensional information from different modalities is completely un-selective, it follows that interference effects may reflect factors other than failures of selective access. For this reason, interference effects are not good evidence of early holistic processing (Melara, Marks, & Potts,1993b).

The present study sought to gather new support for the early holistic hypothesis and its claim that access to information from interacting dimensions can be completely un-selective during the early stages of perceptual processing. The study sought to do this using a different strategy than has been used heretofore. Most of the time in each experiment was spent in a *complex distance task*. On each trial, a pair of small circles appeared on a computer screen. Across trials, the circles appeared in a total of twenty-one different positions on the screen. These positions were arranged along the horizontal and vertical dimensions of the screen in three rows and seven columns so as to define an array such as is shown in Figure 3. The participant was required on each trial to indicate whether or not the test circles were *two or fewer position units apart in terms of the horizontal dimension* of the position array.

Insert Figure 3 about here

The complex distance task could be performed on the basis of two decision rules. 1) Under the one-dimensional rule, performance in the task was characterized by decisional separability; response decisions were based on the distance between the test circles on the focal horizontal dimension. Under the two-dimensional rule, performance in the task was not characterized by decisional separability; response decisions were based on the aggregate distance between the test circles on the non-focal vertical and the focal horizontal dimensions. The required discrimination could be performed more easily on the basis of the one- than the two-dimensional rule. Under the two-dimensional rule, the discrimination could be performed more easily to the extent that focal distance was weighted more heavily than non-focal distance in the aggregate distance upon which response decisions were based (this is shown in more detail in the Method section). Of course, with focal distance given no weight at all, the two-dimensional rule becomes the one-dimensional rule. Figure 4 illustrates the two decision rules.

Insert Figure 4 about here

Pilot work suggested that performance of the complex distance task would be based on the two-dimensional decision rule. The early holistic and dimensional similarity hypotheses both accommodated this pattern. Under the early holistic hypothesis, use of the two-dimensional rule was accommodated because access to information from interacting dimensions can be completely un-selective. Under the dimensional similarity hypothesis, use of the two-dimensional rule was accommodated because access to information from interacting dimensions is always somewhat un-selective. This is because 1) stimulus-level processing always occurs for interacting dimensions and 2) stimulus-level processing does not allow information from one of two interacting dimensions to be considered independently of information from the other dimension. Thus, under both hypotheses, participants used the two-dimensional rule in the complex distance task because access to information from the interacting dimensions was at least somewhat un-selective.

The question at issue in the study was exactly what sort of two-dimensional decision rule would be used in performing the complex distance task; more specifically, the question was whether focal and non-focal distance would be given equal weight in the aggregate distance upon which response decisions were based. The plan was to ask this question during early and later stages of processing in the task. The goal was to show that the two dimensions were given equal weight during early processing and unequal weight during later processing. This would be used to argue that access to information from the two dimensions was completely un-selective during early processing and selective during later processing, as is predicted by the early holistic hypothesis. Of course, use of a particular decision rule is not in and of itself diagnostic with respect to either of the hypotheses under consideration. Traditionally, decision questions have been seen as orthogonal to questions regarding the selectivity of access (Maddox, 1992). The goal, however, was to demonstrate a pattern of early and late decision-rule usage that could not easily be explained without positing a change from un-selective to selective access.

Each experiment of the study also included a *simple distance task*, which was the same as the complex distance task except that only the middle row of the position array was used. The plan was that performance in this task be compared with performance in trials of the complex task on which the test circles did not differ on the vertical dimension. In this way, it would be possible to gauge the cost of attending to two rather than one dimension.

Experiment 1

This experiment was the first step in building a case for the early holistic hypothesis. Participants performed the complex and simple distance tasks under a response signal procedure that induced speeded responding. It was assumed that the tasks would tap early perceptual processing when performed under these conditions.

The early holistic hypothesis predicted that focal and non-focal distance might be given equal weight in the complex distance task. Although the required discrimination could be performed more easily to the extent that focal distance was given greater weight than non-focal distance, access to information from interacting dimensions can be completely un-selective during early perceptual processing. Thus, the two dimensions might have to be given equal weight because access was un-selective. In contrast, the dimensional similarity hypothesis predicted that focal distance would be given greater weight than non-focal distance in the complex distance task. The required discrimination could be performed more easily to the extent that this was done, and access of information from interacting dimensions is always somewhat selective. The objective was to gather support for the early holistic hypothesis by showing that focal and non-focal distance were given equal weight in the complex distance task.

Notice that, in contrast to the case with the correlated-values task, the use of non-focal information could not have been *induced* in the complex distance task by decision factors. This follows because the required discrimination could be performed more easily to the extent that this information was excluded. Thus, if focal and non-focal distance were given equal weight, this could not have been done in the service of a more optimal decision, as with the correlated-values task. Of course, other decision factors might have caused the equal weighting of focal and non-focal distance. The plan was that these other factors be dealt with in further experiments if evidence for equal weighting was observed.

Method

Participants. The participants were 18 students at the George Washington University. They received extra credit in a psychology course in exchange for their efforts.

Stimuli. Each of the test circles measured 3 mm in diameter. Pairs of adjacent positions in the position array were separated by 8 mm on the horizontal and the vertical dimension.

Decision rules for the complex distance task. Under the one-dimensional rule, response decisions were based on the distance between the test circles on the focal horizontal dimension. Under the two-dimensional rule, response decisions were based on the aggregate distance between the test circles on the non-focal vertical as well as the focal horizontal dimension. Although this was not the way the task was supposed to be performed, this decision rule was nonetheless capable of producing accurate results. This was shown was follows: It was assumed that focal and non-focal distance would be aggregated according to the Euclidean metric. This seemed reasonable, inasmuch as the distances pertained to a space that is generally understood in Euclidean terms. It was assumed that focal distance would be given equal or greater weight, relative to non-focal distance, in the aggregate distance upon which decisions were based. Given these assumptions, simple calculation showed that, for positive trials, the aggregate distance between the test circles was always less than or equal to 2.83 position units, and, for negative trials, the aggregate distance was always greater than or equal to 3 units (See Figure 4). With focal distance given greater weight than non-focal distance, the aggregate distance on positive trials was always less than or equal to a value that lay between 2 and 2.83 units, with the value being closer to 2 the less weight was given to non-focal distance. The aggregate distance on negative trials was again always greater than or equal to 3 units.

More importantly, the required discrimination could be performed more easily, under the two-dimensional rule, to the extent that focal distance was given greater weight than non-focal distance. With focal and non-focal distance given equal weight, the most difficult discrimination contrasted distances of 2.83 and 3 units. To the extent that focal distance was given greater weight than non-focal distance, the discrimination became easier, becoming easiest if non-focal distance was given no weight at all.

Design. The test items for the complex distance task were created with the following three-step procedure. 1) 84 items were created for which the focal/horizontal distance between the test circles was 0. These items were created as follows: Three items were constructed for each of the seven horizontal positions in the stimulus set. The three items for a given horizontal position differed in the vertical positions of the test circles. Across the three items, the circles appeared in the three unordered pairs of vertical positions that could be formed by sampling twice, without replacement, from the three vertical positions in the stimulus set. Each of the items created in this way was repeated four times in the test sequence. 2) Respectively, 216 and 180 items were created for which the focal/horizontal distance between the test circles was 1 and 2. These items were created as follows: There were, respectively, 6 and 5 possible unordered pairs of horizontal positions for which horizontal distance was equal to 1 and 2. For each of these pairs of horizontal positions, nine items were constructed. The nine items for a given pair of horizontal positions differed in the vertical positions of the test circles. Across the nine items, the circles appeared in the nine ordered pairs of vertical positions that could be formed by sampling twice, with replacement, from the set of three vertical positions in the stimulus set. Each of the items created in this way was repeated four times in the test sequence. 3) Respectively, 72, 54, 36, and 6 items were created for which the focal/horizontal distance between the test circles was 3, 4, 5, and 6. These items were created as follows: There were, respectively, 4, 3, 2, and 1 possible unordered pairs of horizontal positions for which horizontal distance was equal to 3, 4, 5, and 6. For each of these pairs of horizontal positions, nine items were constructed. The nine items for a given pair of horizontal positions differed in the vertical positions of the test circles. Across the nine items, the circles appeared in the nine ordered pairs of vertical positions that could be formed by sampling twice, with replacement, from the set of three vertical positions in the stimulus set. Of the nine items that were created by crossing the first and the seventh horizontal position, the six items were removed for which the test circles did not have the same vertical position. Each of the items created in this way was repeated twice in the test sequence.

In this way 648 items were created for the complex distance task. Of these, 480 were positive items, for which the test circles were two or fewer position units apart on the focal/horizontal dimension, and 168 were negative items, for which the test circles were three or more position units apart on that dimension. The items were presented in a different random order to each participant.

The test items for the simple distance task were created as follows: There were, respectively, 6, 5, 4, 3, 2, and 1 possible unordered pairs of horizontal positions for which horizontal distance was equal to 1, 2, 3, 4, 5, and 6. For each of these pairs of horizontal positions, one item was constructed. In the item for a given pair of horizontal positions, the test circles both had the middle vertical position. Each of the items created in this way was repeated three times in the test sequence. In this way 63 items were created. Of these, 33 were positive items, for which the test circles were two or fewer position units apart on the focal/horizontal dimension, and 30 were negative items, for which the test circles were three or more position units apart on that dimension.

Procedure. The participant was instructed that he/should press the “B” key of the computer keyboard, to indicate a positive response, if the test circles were two or fewer columns apart, in terms of the position array, and the “N” key, to indicate a negative response, if they were not. The sequence of test trials was broken into three parts. The first and third parts, which were of equivalent length, were devoted to the complex distance task. The second part was devoted to the simple distance task. At the beginning of the second part, a message was presented, indicating that the participant could forget about the vertical dimension during that part.

At the beginning of each trial, a "Ready" signal appeared on the computer screen. When the participant pressed the space bar of the computer, a pair of circles appeared. 400 ms after the circles appeared, four asterisks appeared at the bottom of the screen. The participant attempted to make his/her response concurrently with the appearance of the asterisks. If the interval between the appearance of the circles and the participant's response was less than 400 ms, the message "TOO FAST" appeared at the bottom of the screen and remained there until the participant pressed the space bar. If the interval was greater than 650 ms, the message "TOO SLOW" appeared in the same manner. At the beginning of every 6th trial, a message appeared asking the participant to press the space bar to see the position array. When the participant pressed the space bar, the array was presented: twenty-one circles appeared simultaneously in the positions of the array.

Because positive trials were more crucial than negative trials to the objective of the experiment, as will be explained subsequently, an attempt was made to induce good performance on positive trials. The participant was instructed that two kinds of errors were possible in the task. "Yes" errors occurred when the participant erroneously pressed the "B" key. "No" errors occurred when the participant erroneously pressed the "N" key. The participant was told that he/she would receive a $5.00 bonus if he/she made fewer than 20 "No" errors. When the participant made a "No" error, a large red message appeared on the screen. When the participant made a "Yes" error, a small black message appeared. In each case, the message remained on the screen until the participant pressed the space bar.

Results

The following policies were followed in all of the analyses in the present study. The first five trials of each session were classified as practice trials. The data for these trials were excluded from all analyses. The data for trials upon which the response was emitted more than 750 ms after the response signal were also excluded from all analyses. For all of the experiments in the study, these policies resulted in the elimination of less than 2% of the data.

Complex distance task. The goal was to show that focal and non-focal distance were given equal weight in the aggregate distance upon which response decisions were based. Toward that end, performance was analyzed as a function of the focal and non-focal distance between the test circles. On the basis of pilot work, it was expected that performance would decline with focal and non-focal distance on positive trials and improve with focal and non-focal distance on negative trials. It was assumed that this would reflect the use of the two-dimensional decision rule. Under this rule, positive responses should become more difficult with increases in focal and non-focal distance and negative responses should become easier with increases in focal and non-focal distance. In order to achieve the goal of the experiment, the plan was to compare the relative sizes of the focal and non-focal distance effects. The data for positive trials were most important for this plan because the test items for positive trials varied through the same three levels of distance (0,1,2 position units) on the focal and the non-focal dimension. Thus, it was possible to do a matched comparison of the two distance effects.

Table 1 presents the data for positive trials as a function of the focal and non-focal distance between the test circles. The error-rate data were of primary interest, given that the response-signal procedure sought to control response time. Error rate increased with increases in focal and non-focal distance. Because no data were collected when focal and non-focal distance were both 0, the data were not neatly accommodated by an analyses of variance. A regression analysis was therefore conducted to confirm the significance of the patterns that were apparent in the data. The 144 cases in the analysis were the error rates that the 18 individual participants accrued for the 8 different combinations of focal and non-focal distance. The predictor variables were Focal Distance and Non-focal Distance. 17 dummy variables were included to estimate the variability due to Participants. The independent variables were all entered into the regression model simultaneously. Table 2 reports the results of the analysis. Focal and Non-focal Distance both accounted for significant amounts of the variance in the error-rate data. More crucially for the object of the experiment, Focal and Non-focal Distance exerted equivalent effects on performance; the coefficients for Focal and Non-focal Distance did not differ (in fact, the coefficient for Non-Focal Distance was nominally larger than the coefficient for Focal Distance), $t(143) = 1.21$ (All statistical tests were conducted against a significance value of .05).

Insert Table 1 about here

Insert Table 2 about here

The response-time data for positive trials were also analyzed as a function of Focal and Non-focal Distance (see Tables 1 and 2). The pattern was the same as for the error-rate data. Focal and Non-focal Distance both accounted for significant amounts of the variance in the response-time data. The coefficients for Focal and Non-focal Distance did not differ, $t(143) = .60$.

Although they were not diagnostic in the manner of the data for positive trials, because levels of focal and non-focal distance were not matched, the data for negative trials were subjected to exploratory analysis. Table 3 presents these data as a function of Focal and Non-focal Distance. Because no data were collected when Focal Distance was 6 and Non-focal Distance was greater than 0, the data were again not neatly accommodated by analyses of variance. Analyses of variance were therefore conducted on the data for trials on which Focal Distance was less than 6. (This approach was deemed acceptable because only one data point out of ten was excluded and because the data were not as crucial as the data for the positive trials. It was not thought possible to handle the data for positive trials in the same way. Here a similar approach would have excluded two out of eight data points). The analyses revealed that error rate decreased with Focal Distance, linear trend: $F(1,17) = 81.09$, $MSe =$

.051, and with Non-focal Distance, linear trend: $F(1,17) = 18.58$, $MSe = .020$, and that the linear trends in the effects of Focal and Non-focal Distance interacted in the error-rate data, $F(1,17) = 19.87$, $MSe = .016$, because the effect of Non-focal Distance was stronger for smaller values of Focal Distance.

Response time decreased with Focal Distance, linear trend: $F(1,17) = 7.37$, $MSe = 4{,}446$, and with Non-focal Distance, linear trend: $F(1,17) = 4.99$, $MSe = 3{,}178$. The effects of Focal and Non-focal Distance did not interact in the response-time data, $F(4,68) = 1.03$, $MSe = 1{,}239$.

Insert Table 3 about here

Simple distance task. Table 4 presents the data from the simple distance task. For comparison, the data are also shown from the comparable trials in the complex distance task (those on which non-focal distance was 0). The error rate was smaller for the simple distance task than for the comparable trials in the complex distance task, $F(1,17) = 7.64$, $MSe = .020$. The error rate for both tasks was a quadratic function of Focal Distance, $F(1,17) = 71.68$, $MSe = .040$. The effects of Task Type and Focal Distance interacted in the error-rate data, $F(5,85) = 7.10$, $MSe = .016$. The basis of this interaction was the difference between the effects of Task Type for Focal Distance = 2 and for other values of Focal Distance. Although the error rate was generally smaller for the simple than the complex task, this difference was reversed for Focal Distance = 2, $F(1,17) = 13.24$, $MSe = .003$.

Response time was shorter for the simple distance task than for comparable trials in the complex distance task, $F(1,17) = 3.39$, $MSe = 5{,}015$. Response time for both tasks was a quadratic function of Focal Distance, $F(1,17) = 36.87$, $MSe = 3{,}885$. The effects of Task Type and Focal Distance interacted in the response-time data, $F(5,85) = 5.14$, $MSe = 1{,}855$. The basis of this interaction was the difference between the effects of Task Type for Focal Distance = 2 and for other values of Focal Distance. Although response time was generally shorter for the simple than for the complex task, this difference was reversed for Focal Distance = 2, $F(1,17) = 8.51$, $MSe = 703$.

Insert Table 4 about here

Discussion

The test circles were more difficult to identify as being two or fewer position units apart on the focal dimension the further they were from one another on the focal and non-focal dimensions. The test circles were easier to identify as being more than two position units apart on the focal dimension the further they were from one another on the focal and non-focal dimensions. By implication, the task was performed on the basis of the two-dimensional decision rule. Response decisions were based on an aggregate distance that reflected the focal and non-focal distance between the test circles. This is really the only interpretation that is compatible with the contrasting patterns that were observed for positive and negative trials.

Other, less interesting, interpretations of the results are untenable in light of these contrasting results. For example, we can reject an interpretation holding 1) that response decisions were based solely on focal distance, 2) that the test circles had to be aligned on the non-focal dimension before a judgment could be made on the focal dimension, and 3) that alignment was more difficult the more distant the circles were on the non-focal dimension. We can also reject an interpretation holding 1) that response decisions were based solely on focal distance, 2) that the values of the test circles on the non-focal dimension were distracting, and 3) that the amount of distraction increased with the non-focal distance between the test circles. Finally, we can reject an interpretation holding that positive responses were emitted when either focal or non-focal distance was less than or equal to 2. Under all of these interpretations, we would have expected performance on both negative and positive trials to decline as a function of non-focal distance.

Further evidence for the use of a two-dimensional decision rule comes from the analysis that compared the data for the simple distance task and the trials in the complex task on which non-focal distance was 0. In general, performance was better in the simple task. When focal distance was 2, however, performance was better in the complex task. This is what would have been expected if participants had been using a two-dimensional decision rule in the complex task. In the simple task, the smallest distance on negative trials was 3 and the largest distance on positive trials was 2. Thus, the decision boundary would have been a critical value, lying between 3 and 2. In the complex task, with the two-dimensional rule, the smallest distance on negative trials was again 3 and the largest distance on positive trials was in the interval from 2 to 2.83. The decision boundary would have been all of the points whose aggregate distance was equal to a critical value, lying between 3 and a number in the interval from 2 to 2.83 (See Figure 4). We would have expected the critical value to be closer to 2 in the simple than the complex task. On simple task trials for which focal distance was 2, the distance between the test circles was 2. On complex task trials for which focal distance was 2 and non-focal distance was 0, the distance between the test circles was also 2. Because the distance between the circles would have been 2 in both cases, whereas the critical value would have been closer to 2 in the simple case, we would have expected poorer performance in the simple case.

Performance on positive trials in the complex distance task depended as much on non-focal as focal distance. Both error rate and response time demonstrated a nominally but non-significantly stronger relationship with non-focal than with focal distance. These results imply that non-focal distance was given as much weight as focal distance in the aggregate distance upon which response decisions were based. This, in turn, supports the early holistic over the dimensional similarity hypothesis. The required discrimination was easier to perform the more weight was given to focal as opposed to non-focal distance. It would therefore have been advantageous to give more weight to focal as opposed to non-focal distance. Such a weighting scheme should have been possible according to the dimensional similarity hypothesis, because access of information from interacting dimensions is always somewhat selective. Such a weighting scheme might not have been possible according to the early holistic hypothesis, because access of information from interacting dimensions can be completely un-selective during the early stages of processing. Thus, the equivalent weighting that these results imply supports the early holistic over the dimensional similarity hypothesis. Notice that the equivalent weighting of focal and non-focal distance cannot have been induced by decision factors, inasmuch as the required discrimination was easier if focal distance was given greater weight than non-focal distance.

Of course, a number of alternative reasons might be advanced as to why performance on positive trials in the complex distance task depended as much on non-focal as focal distance. One possibility is that participants were insensitive to the decision contingencies of the task. They simply didn’t register that the discrimination could be performed more easily with focal distance given greater weight than non-focal distance. Another possibility is that participants were incapable of giving focal distance greater weight than non-focal distance. Although differential weighting schemes have been implicated in the performance of other cognitive tasks (Nosofsky, 1986, 1987) such schemes may not have been viable in the present case. A third possibility is that participants did give focal distance greater weight than non-focal distance, but that this was hidden as a consequence of the fact that non-focal distance was more salient than focal distance. A fourth possibility is that the difference between the effects of focal and non-focal distance was so small that Experiment 1 was insensitive to it. This possibility is viable inasmuch as the dimensional similarity hypothesis does not say exactly how much more heavily than non-focal distance focal distance should have been weighted.

These alternative accounts might be called into question, and support for the early holistic hypothesis might be enhanced, if a greater effect could be shown for focal than non-focal distance, under conditions that matched the conditions of Experiment 1, except that the early holistic hypothesis predicted selective access of dimensional information. The early holistic hypothesis predicts this during the later stages of perceptual processing. Experiments 2A and 2B therefore sought to show a greater effect for focal than non-focal distance on positive trials in a version of the complex distance task that tapped later-stage processing.

Without testing systematically, it appears that performance on negative trials in the complex distance task depended more on focal than non-focal distance. How can we account for the fact that focal and non-focal distance had unequal effects on negative trials and equivalent effects on positive trials? First, we must note a simple fact of geometry: If a pair of points differ on two dimensions, A and B, and the distance between the points is greater on dimension A than on dimension B, then the Euclidean distance between the points will be increased to a greater degree by an increase in the inter-point distance on dimension A than by an equivalent increase on dimension B. Second, we must note that, on negative trials, the distance between the test circles was always greater on the focal than the non-focal dimension. It follows that, for a given pair of negative test circles, an increase in the inter-circle distance on the focal dimension increased the Euclidean distance between the circles to a greater degree than an equivalent increase on the non-focal dimension. Thus, if participants were basing their responses on the Euclidean distance between the test circles, then we would have expected greater focal than non-focal distance effects on negative trials, even with focal and non-focal distance given equal weight.

In general, performance was better in the simple than the complex distance task. By implication, participants paid a cost for attending to two rather than one dimension. This result will be discussed further later.

Experiments 2A and 2B

Experiments 2A and 2B sought to show a greater effect of focal than non-focal distance on positive trials in a version of the complex distance task that tapped later-stage perceptual processing.

The key difference between these experiments and Experiment 1 was in the temporal parameters. Specifically, the temporal interval between the presentation of the test circles and the response signal was greater in Experiments 2A and 2B than in Experiment 1. Given this difference, it was assumed that Experiments 2A and 2B would tap a later stage of processing than Experiment 1.

As in Experiment 1, it was expected that the two-dimensional decision rule would be used in performing the complex distance task. The question at issue was the relative degree to which focal and non-focal distance would be weighted in the aggregate distance upon which response decisions were based. The early holistic and dimensional similarity hypotheses both predicted that focal distance would be given greater weight than non-focal distance. These predictions followed from two premises. First, the task would be capable of being performed more easily to the extent that focal distance was given greater weight than non-focal distance, for the reasons given earlier. Second, access of dimensional information would be at least somewhat selective. In the case of the early holistic hypothesis, selectivity was predicted because the task would involve later-stage processing. In the case of the dimensional similarity hypothesis, selectivity was predicted because pairs of interacting dimensions are always differentiable, on the basis of attribute-level processing. It was reasoned that, if focal distance was given greater weight than non-focal distance, then a greater effect of focal than non-focal distance would be observed.

It was reasoned that such a result would enhance the support already provided for the early holistic hypothesis, in two senses. First, the result would directly confirm the predictions of the hypothesis. The support that was thereby obtained for the hypothesis would be somewhat mitigated by virtue of the fact that the dimensional similarity hypothesis predicted the same result.

Second, and more important, the result would confirm the support that Experiment 1 provided for the early holistic hypothesis. In that experiment, focal and non-focal distance effects of equivalent size were observed in a task that could be performed more easily with focal distance given greater weight than non-focal distance. This pattern of results was interpreted as an indication that access to dimensional information was completely un-selective in that situation. This, in turn, was taken as support for the early holistic hypothesis. Several other possible interpretations of the effect were noted, however. According to one interpretation, participants were insensitive to the fact that the task could be performed more easily with focal distance given greater weight than non-focal distance. According to another interpretation, participants were incapable of giving greater weight to focal than non-focal distance. According to another interpretation, participants gave greater weight to focal than non-focal distance but this was hidden as a consequence of the fact that non-focal distance was more salient than focal distance. According to yet another interpretation, the difference between the effects of focal and non-focal distance was too small to be detected in Experiment 1. Showing a greater effect of focal than non-focal distance effect in a task that was essentially identical to the task of Experiment 1 would render these alternative interpretations much less plausible.

Experiment 2A

Experiment 2A was an initial attempt at showing a greater effect of focal than non-focal distance on positive trials in a complex distance task that tapped later-stage processing. The experiment was identical to Experiment 1 except in two respects: 1) the interval between the presentation of the test circles and the response signal was greater than in Experiment 1; 2) the reward contingencies were set to reduce “Yes” errors rather than “No” errors as in Experiment 1. The latter change was made to ensure a large enough number of “No” errors that differential effects of focal and non-focal distance could be detected.

Method

Participants. The participants were 14 students at the George Washington University. They received extra credit in a psychology course in exchange for their efforts.

Stimuli. The stimuli were the same as in Experiment 1.

Design. The design was the same as in Experiment 1.

Procedure. The procedure was the same as in Experiment 1 except for the following changes. 1) The asterisks appeared 1000 rather than 400 ms after the circles appeared. 2) The participant was told that he/she would receive a $5.00 bonus if he/she made fewer than 20 “Yes” errors and fewer than 100 “No” errors. When the participant made a “Yes” error, a large red message appeared to that effect. When the participant made a “No” error, a small black message appeared to that effect.

Results

Complex distance task. Table 5 presents the data for positive trials as a function of the focal and non-focal distance between the test circles. Error rate increased with increases in focal and non-focal distance. A regression analysis was conducted to confirm the significance of these patterns. The 112 cases in the analysis were the error rates that the 14 individual participants accrued for the 8 different combinations of focal and non-focal distance. 13 dummy variables were included to estimate the variability due to Participants. In other respects, the analysis was identical to the analyses that were done in Experiment 1. Table 6 reports the results of the analysis. Focal and Non-focal Distance both accounted for significant amounts of the variance in the error-rate data. Focal Distance had a stronger impact than Non-focal Distance; the coefficient for Focal Distance was significantly larger than the coefficient for Non-focal Distance, $t(111) = 1.70$ (one-tailed).

<u>Insert Table 5 about here</u>

<u>Insert Table 6 about here</u>

The response-time data for positive trials were also analyzed as a function of Focal and Non-focal Distance (see Tables 5 and 6). Focal and Non-focal Distance both accounted for significant amounts of the variance in the response-time data. The coefficients for Focal and Non-focal Distance did not differ, $t(111) = .95$.

Table 7 presents the data for negative trials as a function of Focal and Non-focal Distance. An analysis of variance revealed that error rate decreased as a function of Focal Distance, linear trend: $F(1,13) = 15.33$, $MSe = .019$, and as a function of Non-focal Distance, linear trend: $F(1,13) = 12.71$, $MSe = .009$, and that the linear trends in the effects of Focal and Non-focal Distance interacted in the error-rate data, $F(1,35) = 13.16$, $MSe = .008$, because the effect of Non-focal Distance was stronger for smaller values of Focal Distance.

Response time decreased as a function of Focal Distance, linear trend: $F(1,13) = 8.36$, $MSe =$ 1,920, and as a function of Non-focal Distance, linear trend: $F(1,13) = 4.37$, $MSe =$ 1,107. The effects of Focal and Non-focal Distance did not interact in the response-time data, $F(4,52) < 1$.

<u>Insert Table 7 about here</u>

Simple distance task. Table 8 presents the data from the simple distance task and the comparable trials in the complex distance task. The error rates for the simple task and the comparable trials in the complex task did not differ, $F(1,13) = 2.52$, $MSe = .020$. The error rates for both tasks were linear, $F(1,13) = 23.93$, $MSe = .002$, and quadratic functions of Focal Distance, $F(1,13) =$ 16.49, $MSe = .008$. The effects of Task Type and Focal Distance interacted in the error-rate data, $F(5,65) = 7.62$, $MSe = .003$. The basis of this interaction was the difference between the effects of Task Type for Focal Distance 3 and for other values of Focal Distance. Although the error rates for the simple than the complex task generally did not differ, for Focal Distance = 3, the error rate for the simple task was smaller than the error rate for the complex task, $F(1,13) = 11.23$, $MSe = .014$.

Response time did not differ in simple task and the comparable trials of the complex task, $F(1,13) < 1$. Response time for both tasks was neither a linear, $F(1,13) < 1$, nor a quadratic function of

Focal Distance, $F(1,13) = 3.77$, $MSe = 2{,}563$. . The effects of Task Type and Focal Distance did not interact in the response-time data, $F(5,65) < 1$.

Insert Table 8 about here

Experiment 2B

Although Experiment 2A demonstrated a larger effect of focal than non-focal distance, the results were not particularly robust. Experiment 2B sought to replicate these results. The experiment was identical to Experiment 2A except that the horizontal and vertical distance between adjacent positions in the position array was greater. The rationale for this change was as follows. Because the distances between the circles would be greater in Experiment 2B than Experiment 2A, the task would be easier in Experiment 2B than in Experiment 2A. A later processing stage might therefore have been reached in Experiment 2B than in Experiment 2A at the point that the response signal was presented. If this was the case, Experiment 2B might have a better chance than Experiment 2A of showing differential effects of focal and non-focal distance.

Method

Participants. The participants were 36 students at the George Washington University. They received extra credit in a psychology course in exchange for their efforts.

Stimuli. The stimuli were the same as in Experiments 1 and 2A except that the horizontal and vertical distance between adjacent positions in the position array was 11 rather than 8 mm.

Design. The design was the same as in Experiments 1 and 2A.

Procedure. The procedure was the same as in Experiment 2A.

Results

Complex distance task. Table 9 presents the data for positive trials as a function of the focal and non-focal distance between the test circles. Error rate increased with increases in focal and non-focal distance. A regression analysis was conducted to confirm the significance of these patterns. The 288 cases in the analysis were the error rates that the 36 individual participants accrued for the 8 different combinations of focal and non-focal distance. 35 dummy variables were included to estimate the variability due to Participants. In other respects, the analysis was identical to the analyses that were done in Experiments 1 and 2A. Table 10 reports the results of the analysis. Focal and Non-focal Distance both accounted for significant amounts of the variance in the error-rate data. More crucially for the object of the experiment, Focal Distance had a stronger impact than Non-focal Distance; the coefficient for Focal Distance was larger than the coefficient for Non-focal Distance, $t(287) = 1.74$ (one-tailed).

Insert Table 9 about here

Insert Table 10 about here

The response-time data for positive trials were also analyzed as a function of Focal and Non-focal Distance (see Tables 9 and 10). Focal and Non-focal Distance both accounted for significant amounts of the variance in the response-time data. The coefficients for Focal and Non-focal Distance did not differ, $t(287) = .16$.

Table 11 presents the data for negative trials as a function of Focal and Non-focal Distance. An analysis of variance revealed that error rate decreased as a function of Focal Distance, linear trend: $F(1,35) = 50.33$, $MSe = .013$, and as a function of Non-focal Distance, linear trend: $F(1,35) = 21.16$, $MSe = .008$, and that the linear trends in the effects of Focal and Non-focal Distance interacted in the error-rate data, $F(1,35) = 18.34$, $MSe = .007$, because the effect of Non-focal Distance was stronger for smaller values of Focal Distance.

Response time did not vary as a function of Focal Distance, $F(2,70) = 2.83$, $MSe = 1,277$ or as a function of Non-focal Distance, $F(2,70) < 1$. The effects of Focal and Non-focal Distance did not interact in the response-time data, $F(4,140) = 2.28$, $MSe = 660$.

Insert Table 11 about here

Simple distance task. Table 12 presents the data from the simple distance task and the comparable trials in the complex distance task. The error rates for the simple task and the comparable trials in the complex task did not differ, $F(1,35) < 1$. The error rates for both tasks were linear, $F(1,35) = 8.85$, $MSe = .011$, and quadratic functions of Focal Distance, $F(1,35) = 21.24$, $MSe = .009$. The effects of Task Type and Focal Distance interacted in the error-rate data, $F(5,175) = 3.59$, $MSe = .006$. The basis of this interaction was the difference between the effects of Task Type for Focal Distance 3 and for other values of Focal Distance. Although the error rates for the simple than the complex task generally did not differ, for Focal Distance = 3, the error rate was greater for the complex than for the simple task $F(1,35) = 5.97$, $MSe = .014$.

Response time did not differ in simple task and the comparable trials in the complex distance task, $F(1,35) < 1$. Response time for both tasks was neither a linear, $F(1,35) = 1.64$, $MSe = 1,139$, nor a quadratic function of Focal Distance, $F(1,35) < 1$. The effects of Task Type and Focal Distance did not interact in the response-time data, $F(5,175) < 1$.

Insert Table 12 about here

Discussion of Experiments 2A and 2B

The test circles were more difficult to identify as being two or fewer position units apart on the focal dimension the further the circles were from one another on the focal and non-focal dimensions. The test circles were easier to identify as being more than two position units apart on the focal dimension the further the circles were from one another on the focal and non-focal dimensions. By implication, the task was performed on the basis of the two-dimensional decision rule.

Further support for this conclusion comes from the analysis that compared the data for the simple distance task and the trials in the complex task on which non-focal distance was 0. In general, performance in the two tasks did not differ. When focal distance was 3, however, performance was better in the simple task. This is what would have been expected if participants had been using a two-dimensional decision rule in the complex task. As was argued in the discussion of Experiment 1, the critical value for positive vs. negative responses would have been somewhere between 3 and 2 in the simple task, and somewhere between 3 and a number in the interval from 2 to 2.83 in the complex task. Thus, we would have expected the critical value to be closer to 3 in the complex than the simple task. On simple task trials for which focal distance was 3, the distance between the test circles would have been 3. On complex task trials for which focal distance was 3 and non-focal distance was 0, the aggregate distance between the test circles would also have been 3. Because the distance between the test circles would have been 3 in both cases, whereas the critical value would have been closer to 3 in the complex case, we would have expected poorer performance in the complex case.

Of greater interest, the error rate for positive trials depended to a greater degree on focal than non-focal distance. By implication, focal distance was given greater weight than non-focal distance in the aggregate distance upon which response decisions were based.

These results accord with the predictions of both the early holistic and the dimensional similarity hypotheses. According to both hypotheses, these results were to be expected because the experimental task could be performed more easily with focal distance playing a larger role than non-focal distance, and because access to dimensional information was at least somewhat selective.

On balance, though, these results support the early holistic over the dimensional similarity hypothesis because they reinforce the support that Experiment 1 offered for the former hypothesis. In that experiment, equivalent focal and non-focal distance effects were observed even though decision factors dictated that focal distance be given greater weight than non-focal distance. It was concluded that access to information from the focal and non-focal dimensions was completely un-selective and that this argued for the early holistic hypothesis. Several other possible interpretations of the results were noted, however. It was suggested 1) that participants might have been insensitive to the fact that focal distance should be given greater weight than non-focal distance, 2) that participants might have been incapable of giving focal distance greater weight than non-focal distance. From the fact that focal distance had a stronger effect than non-focal distance in the present experiment, we can infer that neither of these problems existed in this experiment. Given that the present experiment was quite similar to Experiment 1, we can infer that, most likely, neither of these problems existed in Experiment 1. The support that Experiment 1 offered for the early holistic hypothesis is thereby reinforced.

It was also suggested that participants in Experiment 1 might have given focal distance greater weight than non-focal distance, as the dimensional similarity hypothesis predicts, but that this might not have been detected, either 1) because non-focal distance was more salient than focal distance, or 2) because the difference between the effects of focal and non-focal distance was too small for Experiment 1 to detect. The stronger effect of focal than non-focal distance in the present experiment calls these accounts into question. According to the dimensional similarity hypothesis, the difference in weighting between focal and non-focal distance should have been no greater in Experiments 2A and 2B than in Experiment 1. Thus, if the difference went undetected in Experiment 1, it should also have gone undetected in Experiments 2A and 2B.

In both experiments, focal distance was only a slightly better predictor of performance than non-focal distance. By implication, access of dimensional information only gradually becomes selective in the complex distance task.

On negative trials, performance improved as a function of focal and non-focal distance, with the effect of focal distance being apparently stronger than the effect of non-focal distance. Again, these results are not particularly diagnostic. By the argument detailed in the discussion of Experiment 1, this is what would have been expected if participants had used a two-dimensional Euclidean decision rule, regardless of whether focal distance was given greater weight than non-focal distance.

Whereas performance was better on the simple than the complex distance task in Experiment 1, performance on the two tasks did not differ in Experiments 2A and 2B. The key to this discrepancy is probably the longer interval that elapsed in Experiments 2A and 2B between the presentation of the test circles and the response signal. Participants were under less speed stress in Experiments 2A and 2B. The differences that showed up under speed stress in Experiment 1 did not show up under these more relaxed conditions.

One loose end remains. Experiment 1 observed equivalent effects of focal and non-focal distance with a short response interval and payoff conditions that discouraged “No” errors. Experiments 2A and 2B observed differential effects of focal and non-focal distance with a long response interval and payoff conditions that discouraged “Yes” errors. Prudence dictates that equivalent effects of focal and non-focal distance be confirmed with a short response interval and payoff conditions that discourage “Yes” errors. Experiment 3 sought to do this.

Experiment 3

Method

Participants. The participants were 20 students at the George Washington University. They received extra credit in a psychology course in exchange for their efforts.

Stimuli. The stimuli were the same as for Experiments 1 and 2A.

Design. The design was the same as for Experiments 1, 2A and 2B.

Procedure. The procedure was the same as for Experiments 2A and 2B, except that the interval between the presentation of the test circles and the response signal was 400 ms, as in

Experiment 1.

Results

Complex distance task. Table 13 presents the data for positive trials as a function of the focal and non-focal distance between the test circles. Error rate increased with increases in focal and non-focal distance. A regression analysis was conducted to confirm the significance of these patterns. The 160 cases in the analysis were the error rates that the 20 individual participants accrued for the 8 different combinations of focal and non-focal distance. 19 dummy variables were included to estimate the variability due to Participants. In other respects, the analysis was identical to the analyses that were done in Experiments 1, 2A, and 2B. Table 14 reports the results of the analysis. Focal and Non-focal Distance both accounted for significant amounts of the variance in the error-rate data. More crucially for the object of the experiment, Focal and Non-focal Distance were equally strong predictors of error rate; the coefficients for the two forms of distance did not differ, $t(159) = .20$

Insert Table 13 about here

Insert Table 14 about here

The response-time data for positive trials were also analyzed as a function of Focal and Non-focal Distance (see Tables 13 and 14). Focal and Non-focal Distance both accounted for significant amounts of the variance in the response-time data. The coefficients for Focal and Non-focal Distance did not differ, $t(159) = .32$.

Table 15 presents the data for negative trials as a function of Focal and Non-focal Distance. An analysis of variance revealed that error rate decreased as a function of Focal Distance, linear trend: $F(1,19) = 29.14$, $MSe = .041$, and as a function of Non-focal Distance, linear trend: $F(1,19) = 13.10$, $MSe = .021$, and that the linear trends in the effects of Focal and Non-focal Distance interacted in the error-rate data, $F(1,19) = 15.34$, $MSe = .018$, because the effect of Non-focal Distance was stronger for smaller values of Focal Distance.

Response time decreased as a function of Focal Distance, linear trend: $F(1,19) = 5.46$, $MSe = 5{,}699$, but did not vary as a function of Non-focal Distance, $F(2,38) = 1.49$, $MSe = 2{,}281$. The effects of Focal and Non-focal Distance interacted in the response-time data, $F(4,76) = 4.19$, $MSe = 1{,}229$, because the effect of Focal distance was larger for small than for large values of Non-focal distance.

<u>Insert Table 15 about here</u>

Simple distance task. Table 16 presents the data from the simple distance task and the data from the comparable trials in the complex distance task. The error rates for the simple task and the comparable trials in the complex task did not differ, $F(1,19) < 1$. The error rates for the two tasks were linear, $F(1,19) = 7.82$, $MSe = .023$, and quadratic functions of Focal Distance, $F(1,19) = 23.18$, $MSe = .044$. The effects of Task Type and Focal Distance did not interact in the error-rate data, $F(5,95) = 1.62$, $MSe = .023$.

Response time did not differ in the simple task and the comparable trials in the complex task, $F(1,19) < 1$. Response time for both tasks was a linear, $F(1,19) = 30.30$, $MSe = 3{,}727$, but not a quadratic function of Focal Distance, $F(1,195) = 3.13$, $MSe = 5{,}828$. The effects of Task Type and Focal Distance interacted in the response-time data, $F(5,95) = 2.50$, $MSe = 2{,}102$. The basis of this interaction was the difference between the effects of Task Type for Focal Distance = 3 and for other values of Focal Distance. Although response times for the simple and the complex task generally did not differ, at Focal Distance = 3, response time was greater for the complex than for the simple task $F(1,19) = 10.38$, $MSe = 1{,}824$.

<u>Insert Table 16 about here</u>

Discussion

The basic pattern of Experiment 1 was replicated here. Most importantly, performance depended to the same degree on the focal and non-focal distance between the test circles. The most notable difference between the two sets of results emerges in the comparison between the data for the simple distance task and the comparable trials in the complex distance task. Two discrepancies are worthy of note. First, in Experiment 1, performance was significantly better in the simple than the complex distance task. In Experiment 3, however, this was not the case. The pattern of Experiment 1 was nominally but not significantly present. Although its exact basis is unclear, this discrepancy may reflect the difference in payoff criteria between the two experiments. Second, in Experiment 1, performance in the simple distance task was disproportionately bad for Focal Distance = 2. In Experiment 3, however, performance in the complex distance task was disproportionately bad for Focal Distance = 3. The reason for this discrepancy is again unclear. Recall, however, from the previous discussion, that the patterns of both experiments can be taken as evidence for the use of the two-dimensional decision rule. In that sense, then, the two sets of results cohere.

General Discussion

The results of four experiments supported the early holistic hypothesis over the dimensional similarity hypothesis. The experiments explored perceptual processing with respect to a pair of interacting dimensions. Participants in each experiment performed a task that required them to evaluate stimuli on one of the two dimensions along which they varied. The task could be performed in two ways: 1) on the basis of information from the dimension that was focal to the judgment required, and 2) on the basis of information from the non-focal as well as the focal dimension. The task could be performed more easily to the extent that it was performed solely on the basis of focal information.

The task of Experiments 1 and 3 was designed to tap early stages of perceptual processing. Information from the focal and non-focal dimensions exerted equivalent effects on performance of the task. By implication, the task was performed on the basis of a decision rule that gave equal weight to focal and non-focal information. One interpretation of this result is that equal weight was given because access to dimensional information was completely un-selective. Such a lack of selectivity is consistent with the early holistic hypothesis and inconsistent with the dimensional similarity hypothesis. This interpretation is not conclusive, however, inasmuch as the results could have reflected other secondary factors, such as insensitivity to decision factors, incapacity for relative weighting of stimulus dimensions, the relative salience of focal and non-focal distance, or the insensitivity of Experiments 1 and 3 to differences in the weighting of focal and non-focal distance.

The task of Experiments 2A and 2B was designed to tap a later stage of perceptual processing than the task of Experiments 1 and 3. Focal information exerted a larger effect on performance of the task than non-focal information. By implication, the task was performed on the basis of a decision rule that gave greater weight to focal than non-focal information. Inasmuch as the secondary factors mentioned earlier should have been present in Experiments 2A and 2B as well as Experiments 1 and 3, the results of Experiments 2A and 2B suggest that the results of Experiments 1 and 3 do not reflect such factors. Taken together, the results of the four experiments support the early holistic hypothesis over the dimensional similarity hypothesis.

Notice that the task of the present study bears some resemblance to both the correlated- and the orthogonal values tasks. The task resembles the correlated-values task in that non-focal as well as focal information is used in performing it. Notice, however, that, whereas the use of non-focal information may be induced by decision factors in the correlated-values task, this is not the case in the present task, because the required discrimination can be performed more easily to the extent that non-focal information is excluded. The task resembles the orthogonal-values task in the absence of a useful correlation between values on the focal and non-focal dimensions (actually, a small negative correlation (-.231) exists between values on the two dimensions, as a consequence of the fact that no pair of circles exists with zero distance on the focal and non-focal dimensions; this correlation cannot be used to guide responding, though, in contrast to the case of the correlated-values task). Notice, however, that, whereas non-focal information is irrelevant to performance of the orthogonal-values task, non-focal information is relevant to the performance of the present task. The task can be performed most easily if non-focal information is excluded, but it can be successfully performed on the basis of an aggregation of focal and non-focal information.

Support for the early holistic hypothesis appeared here in a somewhat different guise than in past work. Functional relationships were demonstrated between dimensional information and measures of performance. Functional relationships such as these have not typically been demonstrated in past work. One common strategy has been to measure the size of the redundancy and/or the interference effect, aggregated across stimulus values on the focal and non-focal dimensions, as a function of variables of interest (Melara & Day,1992; Melara & Marks, 1990a; Melara & Marks, 1990b; Melara, Marks, & Potts,1993a; Melara & Mounts, 1994; Mounts & Melara, 1995). Another common strategy has been to compare performance on stimulus items that have congruent and incongruent values on two stimulus dimensions, where each of the dimensions in question has only two values (Melara & Marks, 1990a; Melara, Marks, & Potts, 1993a) (In one case, the stimulus dimensions had more than two values, but here the comparison of the congruent and incongruent cases involved a complex estimation process (Melara & Mounts, 1994)).

The nearest thing, in past work, to the functional relationships of the present study has been observed in tasks that combine elements of the correlated- and orthogonal-values tasks (Melara & Marks, 1990b; Mounts & Melara, 1995). These tasks have suffered, however, from the same flaw that complicates interpretation of the simple version of the correlated-values task - that is, the use of non-focal information may have been induced by the decision rule. The present task does not suffer from this flaw.

It may be necessary to explore functional relationships such as were demonstrated here in order to choose between the early holistic and dimensional similarity hypotheses. Both hypotheses can accommodate the impact of non-focal information on perceptual judgments. The hypotheses differ only in the degree of impact that they allow. Whereas the early holistic hypothesis allows non-focal information to have as much impact as focal information, the dimensional similarity hypothesis does not. Thus, in order to choose between the hypotheses, it may be necessary to quantify the impact of focal and non-focal information in the manner of the present study.

Although the present results support the early holistic hypothesis over the dimensional similarity hypothesis, these results may require that we re-formulate the former hypothesis. How might we accommodate the present results under that hypothesis? Access to dimensional information was at least somewhat selective in Experiments 2A and 2B. Thus, we would have to say that the task of these experiments was performed on the basis of a two-dimensional mental representation. Consider the following as an example of such a representation. A given pair of test circles were represented as points in a space whose dimensions were scaled to reflect a relative weighting of focal and non-focal distance. More specifically, the non-focal dimension of this space was shrunken relative to the focal dimension (See Figure 4B). The response decision was based on the Euclidean distance between the points. If this distance was smaller than the critical value, a positive response was emitted. Notice that the focal and non-focal dimensions are *differentiated in terms of scale* in this representation

Representations such as this have been proposed in previous work. It has been suggested that the dimensions of cognitive space expand and contract with their importance for the judgment that is required in a given context. Thus, a dimension that is unimportant for the judgment shrinks relative to a dimension that is important for the judgment (Maddox, 1992; Nosofsky, 1986, 1987).

What kind of representation was used, then, in Experiments 1 and 3? Access to dimensional information was completely un-selective here. Traditional forms of the early holistic hypothesis would hold that the task was performed on the basis of a one-dimensional mental representation. In such a representation, a given pair of test circles would be represented as a single point, corresponding to the Euclidean distance that separated them on the computer screen. If this distance was smaller than the critical value, a positive response would be emitted.

Taken in conjunction with our account of Experiments 2A and 2B, this account is problematic, however. Specifically, it is unclear how we get from the one-dimensional representation of Experiments 1 and 3 to the two-dimensional representation of Experiments 2A and 2B. The former representation is in use 500 ms after the presentation of the test circles. The latter representation is in use 600 ms later. How is the latter representation derived from the former in 600 ms? One possible response to this dilemma involves re-thinking the representation for Experiments 1 and 3. Instead of a one-dimensional representation, we might consider a two-dimensional representation in which the two dimensions are *undifferentiated in terms of scale*.

Thus, building on ideas suggested by Maddox (1992), we might reformulate the early holistic hypothesis as follows, for the case of distance judgments with respect to the horizontal and vertical dimensions of physical space, and possibly for other perceptual judgments and other pairs of interacting dimensions: Horizontal and vertical position are always differentiated in representational terms, even in the early stages of perceptual processing - that is, they are always represented in terms of a two-dimensional mental space. In terms of the cognitive processing required for judgments of distance, however, the two dimensions are undifferentiated in early processing. This is because subjects can only access the aggregate distance between a pair of stimuli. When selective access is required of the distance on one dimension, attention is focused on the dimension in question and the other dimension is ignored. The ultimate impact of focusing attention one of the two dimensions is that the non-focal dimension shrinks to the point that its values are indistinguishable. It is not clear by what mechanism the shrinkage is accomplished, although an inhibitory process of some sort is probably involved (for example, see Melara & Algom, 2003). In any case, once the shrinkage has occurred, differences on the non-focal dimension have no impact on the evaluation process. Shrinkage of the non-focal dimension is a gradual process, however. During the early stages of perceptual processing, the non-focal dimension does not shrink at all. Thus, even though the objective is to evaluate a stimulus on one of the two dimensions, the stimulus is of necessity evaluated on both dimensions.

This formulation of the early holistic hypothesis conceives dimensional differentiation differently than previous formulations. In previous formulations, two interacting dimensions were represented as two mental dimensions if access to dimensional information was selective and as one mental dimension if it was not. In the present formulation, two interacting dimensions are always represented as two mental dimensions. Those dimensions are differentiated in terms of scale if access to dimensional information is selective but undifferentiated in terms of scale if access is un-selective.

The present formulation of the early holistic hypothesis is more similar than previous formulations to the dimensional similarity hypothesis. Most importantly, the present formulation holds, in common with the dimensional similarity hypothesis, that two interacting dimensions are always represented as two mental dimensions, even in the early stages of perceptual processing. In contrast to the dimensional similarity hypothesis, however, the present formulation holds that access to information concerning two interacting dimensions is un-selective during the early stages of processing.

The present formulation of the early holistic hypothesis receives some support from the results of the comparison that was done, in Experiment 1, between performance in the simple distance task and the comparable trials in the complex distance task. In both cases, the vertical distance between the test circles was 0 and the horizontal distance varied from 1 to 6. Yet performance was better in the simple distance task. Assuming that this result is reliable (and that the failure to replicate it in Experiment 3 has some reasonable explanation), one possible explanation for the result is that the test circles were represented in a two-dimensional mental space for the complex task and in a one-dimensional space for the simple distance task. There are, of course, other possible explanations for the result. For example, the complex task required that participants attend to more spatial locations than the simple task. Nonetheless, the result is worth exploring further.

Of course, the above conclusions come with several caveats. The largest concern is that, although the conclusions concern processes of early visual perception, such processes were not directly observed in the present study. The study was set up to allow inferences about perceptual processes on the basis of patterns of decision-rule-usage across several experiments. The inferences that were drawn seem fair and defensible. One would prefer to see the inferences reinforced, however, with results that more directly reflect perceptual processes. This will require a more complex, model-based, approach. Work is underway toward this end.

A secondary concern concerns the response signal procedure that was used to control temporal factors in the different experiments. This procedure was necessary in that the crucial predictions of the early holistic hypothesis concern the early stages of perceptual processing. In order to test these predictions, it was necessary to tap those early processing stages. The response signal procedure is generally accepted as a means of doing this. Nonetheless, it is possible that the procedure encouraged unnatural response tendencies that corrupted the results. One would prefer to see the results reinforced using other, less intrusive, procedures.

Finally, it must be noted that the present results reflect data from only one pair of dimensions. This does not detract from the support offered for the early holistic hypothesis. The dimensional similarity hypothesis holds that access to information from pairs of interacting dimensions is always somewhat selective during the early stages of processing. Thus, the demonstration that access to information from the two dimensions of Experiments 1 and 3 was un-selective is sufficient to make the crucial theoretical point.

It seems clear, nonetheless, that the generality of the present results must be explored in further work. Certainly, the results are unlikely to generalize to all pairs of interacting dimensions. It was crucial to the results observed here that pairs of distances on the two dimensions of the stimulus set were capable of being aggregated to form single distances. In order that this be possible for a given pair of dimensions, each of the dimensions in the pair must have a polar structure, such that values at the two ends of each of the dimensions are maximally different from one another. In addition, in order for the present phenomenon to be studied with a particular pair of dimensions, the two dimensions must be capable of unambiguous alignment. In other words, all participants must agree all of the time as to which end of each dimension holds the low values.

In conclusion, the present results suggest that access of horizontal and vertical position information is un-selective during the early stages of perceptual processing but becomes selective during the later stages of processing. These results support the early holistic hypothesis over the dimensional similarity hypothesis.

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Author Note

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Table 1

Experiment 1: Performance on Positive Trials in Complex Distance Task as Function of Distance between Test Circles on Focal and Non-focal Dimensions

Focal distance (in position units)	Non-focal distance (in position units)		
	0	1	2
		Error rate	
0		.029 (.007)	.081 (.020)
1	.036 (.010)	.027 (.005)	.070 (.017)
2	.042 (.013)	.068 (.014)	.247 (.031)
		Response time	
0		492 (5)	520 (9)
1	500 (7)	497 (7)	528 (9)
2	516 (8)	519 (7)	547 (9)

Note. The standard error of the mean is given in parentheses. Response time means include the 400 ms that elapsed before the response signal appeared.

Table 2

Experiment 1: Regression Analysis of Performance on Positive Trials in Complex Distance Task as Function of Distance between Test Circles on Focal and Non-focal Dimensions

	Coefficient	Standard error	Standardized coefficient	t-value	p-value
		Error rate			
Focal distance	.050	.008	.406	6.31	< .001
Non-focal distance	.062	.008	.507	7.87	< .001
	R^2: .513				
		Response time			
Focal distance	15.01	2.26	.322	6.63	< .001
Non-focal distance	16.70	2.26	.359	7.38	< .001
	R^2:.723				

Table 3

Experiment 1: Performance on Negative Trials in Complex Distance Task as Function of Distance between Test Circles on Focal and Non-focal Dimensions

Focal distance (position units)	Non-focal distance (position units)		
	0	1	2
		Error rate	
3	.646 (.045)	.591 (.055)	.349 (.061)
4	.220 (.041)	.252 (.038)	.194 (.057)
5	.141 (.049)	.160 (.040)	.101 (.049)
6	.070 (.026)		
		Response time	
3	632 (23)	612 (21)	595 (16)
4	598 (21)	595 (19)	574 (16)
5	584 (23)	578 (17)	575 (14)
6	548 (13)		

Note. The standard error of the mean is given in parentheses. Response time means include the 400 ms that elapsed before the response signal appeared.

Table 4

Experiment 1: Performance in Simple Distance Task and comparable trials of Complex Distance Task as Function of Distance between Test Circles on Focal Dimension

	Focal distance (position units)					
	1	2	3	4	5	6
	Error rate					
Complex	.036 (.010)	.042 (.013)	.646 (.045)	.220 (.041)	.141 (.049)	.070 (.026)
Simple	.037 (.015)	.108 (.021)	.385 (.040)	.165 (.052)	.098 (.039)	.039 (.026)
	Response time					
Complex	500 (7)	516 (8)	632 (23)	598 (21)	584 (23)	548 (13)
Simple	506 (9)	542 (14)	576 (22)	559 (19)	545 (15)	546 (21)

Note. The standard error of the mean is given in parentheses. Response time means include the 400 ms that elapsed before the response signal appeared.

Table 5

Experiment 2A: Performance on Positive Trials in Complex Distance Task as Function of Distance between Test Circles on Focal and Non-focal Dimensions

Focal distance (in position units)	Non-focal distance (in position units) 0	1	2
		Error rate	
0		.041 (.016)	.030 (.010)
1	.047 (.018)	.038 (.013)	.031 (.008)
2	.066 (.015)	.099 (.026)	.276 (.053)
		Response time	
0		1153 (18)	1161 (19)
1	1156 (18)	1156 (18)	1165 (19)
2	1170 (17)	1165 (17)	1200 (19)

Note. The standard error of the mean is given in parentheses. Response time means include the 1000 ms that elapsed before the response signal appeared.

Table 6

Experiment 2A: Regression Analysis of Performance on Positive Trials in Complex Distance Task as Function of Distance between Test Circles on Focal and Non-focal Dimensions

	Coefficient	Standard error	Standardized coefficient	t-value	p-value
		Error rate			
Focal distance	.071	.012	.482	5.86	< .001
Non-focal distance	.046	.012	.315	3.84	< .001
	R^2: .386				
		Response time			
Focal distance	13.69	2.99	.161	4.57	< .001
Non-focal distance	10.17	2.99	.120	3.39	< .001
	R^2:.887				

Table 7

Experiment 2A: Performance on Negative Trials in Complex Distance Task as Function of Distance between Test Circles on Focal and Non-focal Dimensions

Focal distance	Non-focal distance (position units)		
(position units)	0	1	2
		Error rate	
3	.251 (.056)	.168 (.050)	.073 (.021)
4	.058 (.020)	.048 (.025)	.021 (.012)
5	.041 (.018)	.066 (.021)	.035 (.022)
6	.032 (.023)		
		Response time	
3	1194 (16)	1175 (16)	1178 (15)
4	1170 (20)	1173 (21)	1158 (18)
5	1161 (17)	1159 (18)	1144 (18)
6	1166 (21)		

Note. The standard error of the mean is given in parentheses. Response time means include the 1000 ms that elapsed before the response signal appeared.

Table 8

Experiment 2A: Performance in Simple Distance Task and comparable trials of Complex Distance Task as Function of Distance between Test Circles on Focal Dimension

	Focal distance (position units)					
	1	2	3	4	5	6
	Error rate					
Complex	.047 (.018)	.066 (.015)	.251 (.056)	.058 (.020)	.041 (.018)	.032 (.023)
Simple	.040 (.021)	.063 (.017)	.103 (.045)	.033 (.025)	.024 (.017)	.024 (.024)
	Response time					
Complex	1156 (18)	1170 (17)	1194 (16)	1170 (20)	1161 (17)	1166 (21)
Simple	1158 (22)	1192 (26)	1182 (23)	1180 (21)	1157 (22)	1167 (24)

Note. The standard error of the mean is given in parentheses. Response time means include the 1000 ms that elapsed before the response signal appeared.

Table 9

Experiment 2B: Performance on Positive Trials in Complex Distance Task as Function of Distance between Test Circles on Focal and Non-focal Dimensions

Focal distance (in position units)	Non-focal distance (in position units) 0	1	2
		Error rate	
0		.029 (.008)	.044 (.013)
1	.033 (.012)	.030 (.006)	.076 (.018)
2	.083 (.016)	.116 (.016)	.358 (.042)
		Response time	
0		1149 (8)	1164 (7)
1	1149 (7)	1154 (7)	1158 (8)
2	1159 (8)	1166 (8)	1174 (9)

Note. The standard error of the mean is given in parentheses. Response time means include the 1000 ms that elapsed before the response signal appeared.

Table 10

Experiment 2B: Regression Analysis of Performance on Positive Trials in Complex Distance Task as Function of Distance between Test Circles on Focal and Non-focal Dimensions

	Coefficient	Standard error	Standardized coefficient	t-value	p-value
		Error rate			
Focal distance	.096	.009	.483	10.97	< .001
Non-focal distance	.077	.009	.390	8.85	< .001
	R^2: .541				
		Response time			
Focal distance	8.97	1.84	.105	4.88	< .001
Non-focal distance	9.34	1.84	.109	5.08	< .001
	R^2:.891				

Table 11

Experiment 2B: Performance on Negative Trials in Complex Distance Task as Function of Distance between Test Circles on Focal and Non-focal Dimensions

Focal distance (position units)	Non-focal distance (position units) 0	1	2
		Error rate	
3	.180 (.028)	.144 (.023)	.044 (.011)
4	.036 (.010)	.024 (.004)	.023 (.003)
5	.022 (.011)	.016 (.007)	.004 (.004)
6	.040 (.015)		
		Response time	
3	1169 (10)	1166 (10)	1164 (9)
4	1152 (8)	1154 (8)	1167 (9)
5	1159 (9)	1157 (9)	1151 (10)
6	1160 (10)		

Note. The standard error of the mean is given in parentheses. Response time means include the 1000 ms that elapsed before the response signal appeared.

Table 12

Experiment 2B: Performance in Simple Distance Task and comparable trials of Complex Distance Task as Function of Distance between Test Circles on Focal Dimension

	Focal distance (position units)					
	1	2	3	4	5	6
	Error rate					
Complex	.033 (.012)	.083 (.016)	.180 (.028)	.036 (.010)	.022 (.011)	.040 (.015)
Simple	.037 (.009)	.106 (.029)	.112 (.021)	.019 (.008)	.046 (.018)	.028 (.016)
	Response time					
Complex	1149 (7)	1159 (8)	1169 (10)	1152 (8)	1159 (9)	1160 (10)
Simple	1152 (9)	1163 (10)	1161 (10)	1155 (10)	1149 (10)	1171 (13)

Note. The standard error of the mean is given in parentheses. Response time means include the 1000 ms that elapsed before the response signal appeared.

Table 13

Experiment 3: Performance on Positive Trials in Complex Distance Task as Function of Distance between Test Circles on Focal and Non-focal Dimensions

Focal distance (in position units)	Non-focal distance (in position units) 0	1	2
		Error rate	
0		.132 (.045)	.170 (.045)
1	.144 (.044)	.139 (.037)	.198 (.045)
2	.168 (.047)	.202 (.049)	.447 (.042)
		Response time	
0		514 (12)	550 (13)
1	520 (9)	520 (10)	560 (12)
2	538 (11)	551 (13)	599 (26)

Note. The standard error of the mean is given in parentheses. Response time means include the 400 ms that elapsed before the response signal appeared.

Table 14

Experiment 3: Regression Analysis of Performance on Positive Trials in Complex Distance Task as Function of Distance between Test Circles on Focal and Non-focal Dimensions

	Coefficient	Standard error	Standardized coefficient	t-value	p-value
			Error rate		
Focal distance	.083	.011	.305	7.47	< .001
Non-focal distance	.081	.011	.295	7.24	< .001
		R^2: .782			
			Response time		
Focal distance	22.55	4.38	.264	5.13	< .001
Non-focal distance	27.33	4.38	.322	6.24	< .001
		R^2:.653			

Table 15

Experiment 3: Performance on Negative Trials in Complex Distance Task as Function of Distance between Test Circles on Focal and Non-focal Dimensions

Focal distance (position units)	Non-focal distance (position units) 0	1	2
		Error rate	
3	.441 (.052)	.421 (.049)	.194 (.045)
4	.179 (.037)	.190 (.039)	.153 (.036)
5	.161 (.048)	.151 (.047)	.149 (.048)
6	.108 (.045)		
		Response time	
3	632 (22)	600 (16)	589 (12)
4	577 (16)	569 (12)	590 (18)
5	573 (16)	568 (12)	583 (18)
6	563 (22)		

Note. The standard error of the mean is given in parentheses. Response time means include the 400 ms that elapsed before the response signal appeared.

Table 16

Experiment 3: Performance in Simple Distance Task and comparable trials of Complex Distance Task as Function of Distance between Test Circles on Focal Dimension

	Focal distance (position units)					
	1	2	3	4	5	6
	Error rate					
Complex	.144 (.044)	.168 (.047)	.441 (.052)	.179 (.037)	.161 (.048)	.108 (.045)
Simple	.120 (.039)	.204 (.051)	.316 (.047)	.149 (.040)	.160 (.054)	.100 (.050)
	Response time					
Complex	520 (9)	538 (11)	632 (22)	577 (16)	573 (16)	563 (22)
Simple	516 (12)	561 (20)	589 (24)	568 (17)	551 (16)	544 (23)

Note. The standard error of the mean is given in parentheses. Response time means include the 400 ms that elapsed before the response signal appeared.

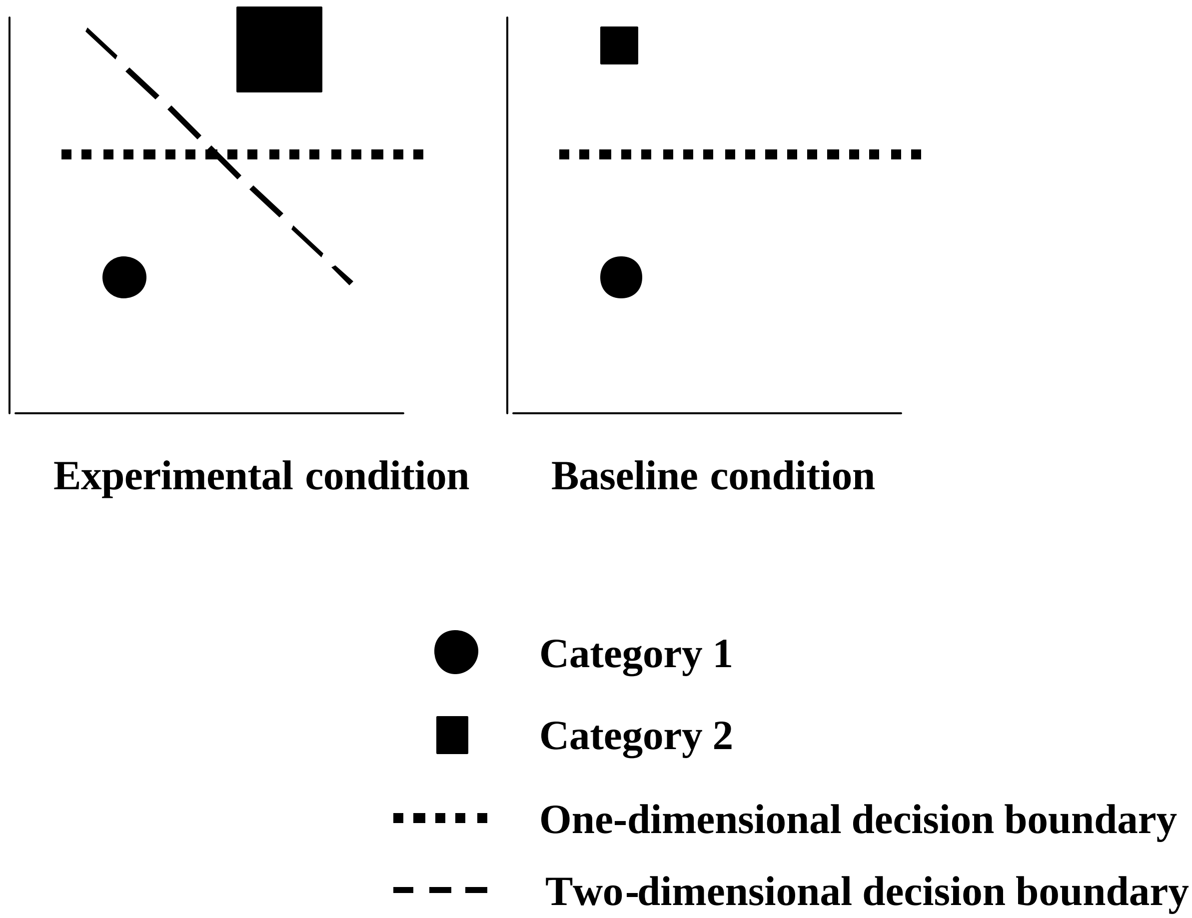
Figure captions

Figure 1. The correlated values task. In the experimental condition, the stimuli vary on the focal dimension, upon which the required categorization is supposed to be based, and on another non-focal dimension, and the values on the two dimensions are correlated. In the baseline condition, the stimuli only vary on the focal dimension. With the one-dimensional rule, response decisions are based on information from the focal dimension. With the two-dimensional rule, response decisions are based on information from both dimensions of the stimulus set.

Figure 2. The orthogonal values task. In the experimental condition, the stimuli vary on the focal dimension, upon which the required categorization is supposed to be based, and on another non-focal dimension, and the values on the two dimensions are un-correlated. In the baseline condition, the stimuli only vary on the focal dimension.

Figure 3. Position array used in experiments of the study.

Figure 4. Hypothetical decision rule for the complex distance task, with focal and non-focal distance given equal weight.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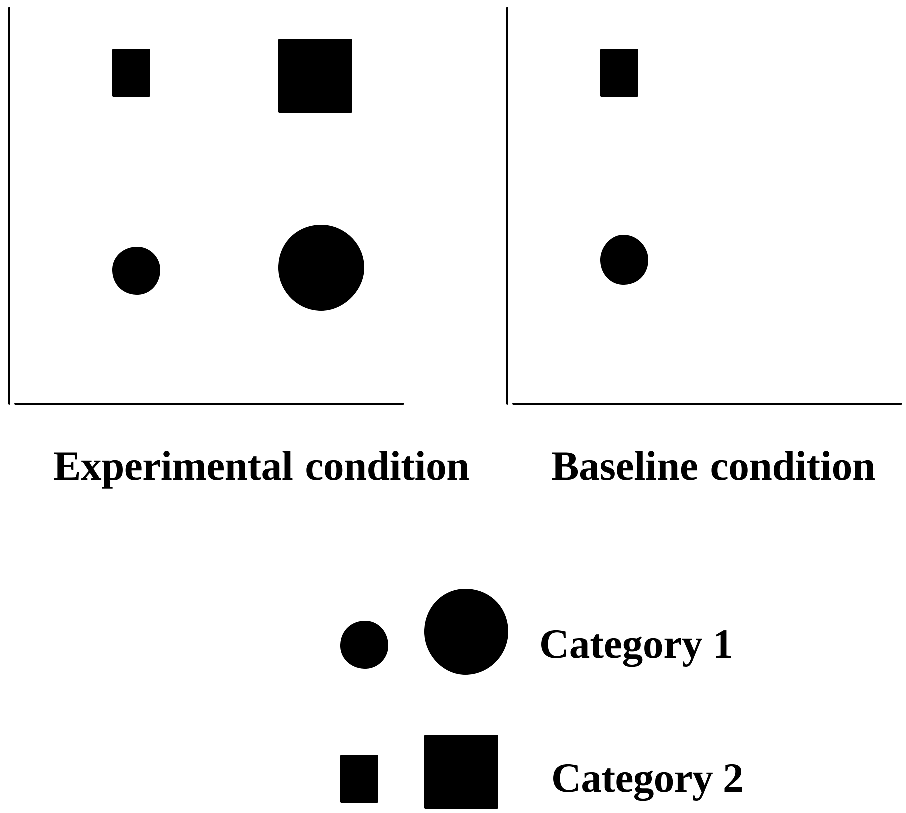
Baseline condition
Category 1
Category 2
One-dimensional decision boundary
Two-dimensional decision boundary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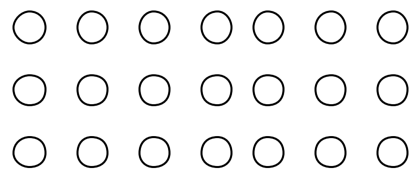
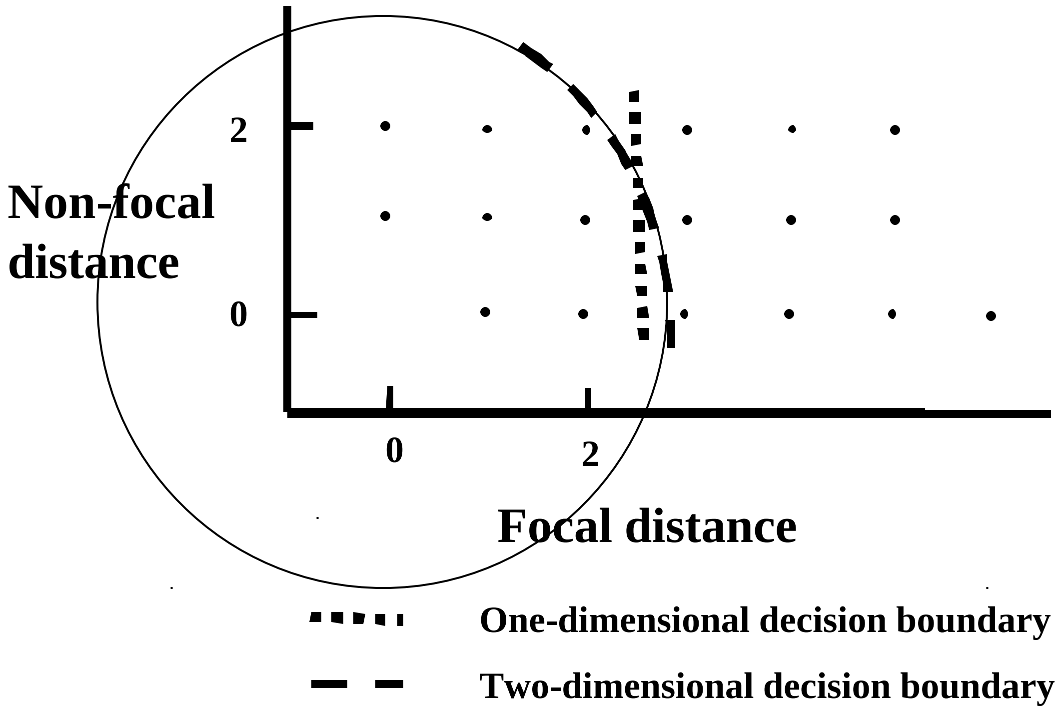
Category 2




2
Non-focal
distance
0
0
2
Focal distance
One-dimensional decision boundary
Two-dimensional decision boundary