Absolute and relative effects of similarity and distance on grouping

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Abstract. Four experiments are reported, the aim of which was to explore the achromatic-colour and distance relations that determine the probability of achromatic surfaces grouping perceptually. The first two experiments were performed to test Wertheimer’s conjecture that similarity and dissimilarity of achromatic colours jointly determine grouping. The results indicate that only similarity of achromatic colours determines grouping. Data from the other two experiments show that grouping is determined by absolute, relative, and Gillam’s distances. These findings agree with previous literature showing that different algorithms or mechanisms determine grouping by similarity and grouping by distance. Additionally, these findings show that the single factor of grouping by distance also depends on multiple algorithms or mechanisms.

1 Introduction
On a two-dimensional phenomenal plane, the probability of achromatic surfaces forming a group depends on the relations between the attributes of the surfaces (Wertheimer 1923). The object of the present study was to explore the relations between achromatic colours of surfaces and the kinds of distances between surfaces that could determine grouping.

Figure 1a shows two rows of squares. Subjects tend to report that in the top row the central square groups with the right square, and that in the bottom row the central square groups with the left square (Oyama et al 1999; Quinn et al 1993; Rock et al 1992). The possibility that these reports depend only on the similarity of achromatic colours is suggested by the finding that, when randomly interspersed dark-grey squares are mixed with randomly interspersed light-grey squares, the extent of the segregation of one group of squares from the other group of squares is a single-valued function of the difference in achromatic colour between the dark and light squares (Beck et al 1991). On the other hand, it is a plausible conjecture that grouping is jointly determined by the similarity and by the dissimilarity of achromatic colours of surfaces (Luchins and Luchins 1998, page 272; Wertheimer 1923). For example, in the top row in figure 1a, when the achromatic colour of the central square progressively approaches the achromatic colour of the left square, both the similarity of the achromatic colours

Figure 1. Examples of grouping by (a) similarity of achromatic colours and (b) distance. Subjects tend to report that, in the top row of squares, the central square groups with the right square; and that, in the bottom row, the central square groups with the left square. In each row of disks subjects tend to report that the central disk groups with the left disk.
of these squares and the dissimilarity of the achromatic colours of the central and right squares progressively increase. It is possible that a progressive increase in the probability of the central and left squares forming a group is jointly determined both by the progressive increase in this similarity and by the progressive increase in this dissimilarity.

The following two experiments were designed to test whether perceptual grouping depends on similarity and on dissimilarity of achromatic colours. Stimuli composed of two squares and stimuli composed of three squares were used. In stimuli composed of two squares, grouping can depend only on similarity of achromatic colours. In stimuli composed of three squares, dissimilarity of achromatic colours can also affect grouping. The possible effect of dissimilarity of achromatic colours should be revealed by different probabilities of identical pairs of squares grouping in these stimuli.

2 Experiment 1
2.1 Method
2.1.1 Subjects. Subjects were thirty-seven university students with normal or corrected-to-normal vision.

2.1.2 Stimuli. In a dark room, each stimulus appeared in the middle of the fronto-parallel 330 mm × 250 mm 0.3 cd m⁻² achromatic screen of an Apple display controlled by a Macintosh computer. A chin-and-forehead rest held the viewing distance at 70 cm.

Stimuli consisted either of two or of three horizontally aligned achromatic uniform squares. The length of the side of the squares was 15 mm and the width of the gaps between squares was 7 mm. Figures 2a to 2c show the contours of stimuli, with A, B, and C denoting the respective squares. Let a, b, and c denote the luminances of A, B, and C, respectively. There were three kinds of stimuli: as in figure 2a with \(a^\hat{1} = 1.9\) cd m⁻² and \(c^\hat{1} = 16.3\) cd m⁻², as in figure 2b with \(a = 1.9\) cd m⁻², or as in figure 2c with \(c = 16.3\) cd m⁻². For each kind of stimulus, \(b^\hat{0} = 0.4, 0.5, 0.7, 0.9, 1.1, 1.5, 1.9, 2.5, 3.3, 4.3, 5.6, 7.3, 9.6, 12.5, 16.3, 21.2, 27.7, 36.2, 47.2, 61.6, \) or \(80.5\) cd m⁻². These 63 stimuli were duplicated and rotated 180°. The series of the resulting 126 stimuli was shown once with stimuli in random order.

![Stimuli](image)

Figure 2. Stimuli used in experiments 1 and 3. Experiment 1 (squares varying in luminance): (a) a central square B flanked by the two squares A and C, (b) only A and B, or (c) only B and C—with one dot representing the fixation point. Experiment 3 (disks of equal luminance): (d) a red disk Y flanked by two white disks X and Z, (e) only X and Y, or (f) only Y and Z—the positions of X and Z were fixed and the position of Y varied horizontally.

Stimuli were displayed as follows. One 1 mm × 1 mm 17 cd m⁻² red square fixation point appeared for 1.5 s with a 0.2 s acoustic signal produced at its onset. In all stimuli, the fixation point and B were concentric. In each of figures 2a to 2c, a dot represents the fixation point. The stimulus appeared when the fixation point disappeared. The stimulus was visible until the experimenter typed the subject’s response or until 1 s had passed from the onset of the stimulus. The subsequent fixation point appeared 1 s after the experimenter typed the subject’s response.
2.1.3 Procedure. On the display screen, before the instructions each subject was shown a $9 \times 9$ square matrix of grey and white circles. Filled and unfilled circles in figures 3a and 3b represent these grey and white circles, respectively. The diameter of the circles was 6 mm and the width of the gap between two contiguous circles was 4 mm. As shown in figure 3a, circles were grey in columns 1 to 7 and white in columns 8 to 9 with the grey circle in row 1 and column 6 indicated by an arrow. Each subject concurred that the indicated circle formed the left group of grey circles. Subsequently, the grey of circles in columns 5 to 7 was turned into the white of circles in columns 8 to 9, thus producing a matrix as that illustrated in figure 3b. Each subject concurred that now the circle in row 1 and column 6, still indicated by an arrow, formed the right group of white circles.

![Figure 3](image-url)

Figure 3. Matrices formed by filled and unfilled circles. In experiment 1, grouping by similarity of achromatic colours was illustrated with matrices as those in (a) and (b) but with grey circles in place of filled circles, and with white circles in place of unfilled circles. In experiments 3 and 4, grouping by distance was illustrated with matrices as those in (c) and (d) but with blue circles in place of filled circles. Arrows show the same circle forming a different group of circles in each of the matrices.

The experimenter first described the stimuli and then read the following instructions to the subject: “Focus on the fixation point and, immediately after it has disappeared, say whether or not you have the impression that in the stimulus there are squares that form a group. If you have such an impression say which are the squares that appear to form a group.” So that subjects did not worry about their response frequencies the following sentence was also read: “The number of cases of squares forming a group is
predetermined randomly by the computer. Squares could appear to form a group in many cases or in few cases or, even, in all cases or in no case.”

2.2 Results and discussion

In stimuli composed of three squares no subject reported that all squares formed a group, two subjects reported that A grouped with C for one stimulus, and one subject reported this for nine stimuli.

The scores for each subject were the following: for each stimulus composed only of A and B, the proportion \( P \) of subject’s reports that A grouped with B; for each stimulus composed only of B and C, the proportion \( P \) of subject’s reports that B grouped with C; and for each stimulus composed of three squares, both the proportion \( P \) of subject’s reports that A grouped with B, and the proportion \( P \) of subject’s reports that B grouped with C.

With a logarithmic horizontal axis, in figure 4 the left diagram shows mean \( P \) for the grouping of A with B, and the right diagram shows mean \( P \) for the grouping of B with C, as a function of \( b \). Vertical lines indicate \( a \) or \( c \). Empty and filled circles show mean \( P \) s for stimuli composed of two and of three squares, respectively.

![Figure 4. Results of experiment 1. With a logarithmic horizontal axis, the left diagram shows the mean proportion \( P \) of reports that A grouped with B (see figures 2a to 2c), and the right diagram shows the mean proportion \( P \) of reports that B grouped with C, as a function of the luminance \( b \) of B. Vertical lines indicate the luminances \( a \) and \( c \) of A and C, respectively. The parameter is the number of squares in the stimulus.](image)

In stimuli composed of two squares, these results show that the probability of B grouping with A or with C increased as \( |a - b| \) or as \( |b - c| \) decreased, respectively. These results confirm that grouping depends on the similarity of achromatic colours.

For levels of factors with variances higher than zero, a 2 (number of squares) by 13 (value of \( b \)) analysis of variance (ANOVA) with scores relative to the grouping of A with B showed that the effect of number of squares was not significant \( (F_{1,36} = 0.0) \) while the interaction was significant \( (F_{12,432} = 2.9, p < 0.005) \), and a 2 (number of squares) by 11 (value of \( b \)) ANOVA with scores relative to the grouping of B with C showed that the effects of both number of squares and the interaction were significant \( (F_{1,36} = 4.3 \) and \( F_{10,360} = 1.9, p < 0.05 \), respectively).

These results show that two squares tend to group perceptually less probably when a third square is present than when no other square is present (effect of number of squares).

The number of squares could have affected grouping by affecting the similarity of achromatic colours. It may be predicted that, if this possibility is true, then the probabilities of reporting grouping and of reporting similarity of achromatic colours should vary with \( b \) approximately in the same way. The following experiment served to test this prediction.
3 Experiment 2
3.1 Method
3.1.1 Subjects. Subjects were thirty university students with normal or corrected-to-normal vision. None of them took part in experiment 1.

3.1.2 Stimuli. Stimuli and presentation of stimuli were the same as in experiment 1.

3.1.3 Procedure. Before the instructions, subjects were asked whether they thought that two different achromatic colours could be similar to each other. All subjects answered affirmatively. The experimenter first described the stimuli and then read the following instructions to the subject: “Focus on the fixation point and, immediately after it has disappeared, say whether or not you have the impression that in the stimulus there are squares with similar achromatic colours. If you have such an impression say which are the squares with similar achromatic colours.” So that subjects did not worry about their response frequencies, the following sentence was also read: “The number of cases of squares with similar achromatic colours is predetermined randomly by the computer. Squares could appear to have similar achromatic colours in many cases or in few cases or, even, in all cases or in no case.”

3.2 Results and discussion
In three stimuli composed of three squares, one subject reported that all achromatic colours were similar to each other, two subjects reported that the achromatic colours of A and C were similar for one stimulus, and one subject reported this for two stimuli.

The scores for each subject were the following: for each stimulus composed only of A and B, the proportion $P$ of subject’s reports that the achromatic colour of A was similar to the achromatic colour of B; for each stimulus composed only of B and C, the proportion $P$ of subject’s reports that the achromatic colour of B was similar to the achromatic colour of C; and for each stimulus composed of three squares, both the proportion $P$ of subject’s reports that the achromatic colour of A was similar to the achromatic colour of B, and the proportion $P$ of subject’s reports that the achromatic colour of B was similar to the achromatic colour of C.

With a logarithmic horizontal axis, in figure 5 the left diagram shows mean $P$ for the similarity of the achromatic colours of A and B, and the right diagram shows mean $P$ for the similarity of the achromatic colours of B and C, as a function of $b$. Vertical lines indicate $a$ or $c$. Empty and filled circles show mean $P$s for stimuli composed of two and of three squares, respectively.

As expected, for each kind of stimulus these results show that the probability of subjects reporting the similarity of the achromatic colours of A and B and of B and C increased as $|a - b|$ and $|b - c|$ decreased, respectively.

For levels of factors with variances higher than zero, a 2 (number of squares) by 13 (value of $b$) ANOVA with scores relative to the similarity of the achromatic colours of A and B, and a 2 (number of squares) by 12 (value of $b$) ANOVA with scores relative to the similarity of the achromatic colours of B and C, showed that the effects of number of squares ($F_{1,29} = 15.4$ and $F_{1,29} = 33.4$, respectively) and the interactions ($F_{12,348} = 3.1$ and $F_{11,319} = 3.1$, respectively) were significant at the 0.005 level.

These results show that the achromatic colours of two squares tend to be judged less similar when a third square is present than when no other square is present (effect of number of squares).

Since number of squares affected both the probability of reporting grouping (figure 4) and the probability of reporting similarity of achromatic colours (figure 5) approximately in the same way, the present results suggest that number of squares affects the probability of reporting grouping by affecting the similarity of achromatic colours.
In disagreement with Wertheimer’s (1923) conjecture that dissimilarity codetermines grouping, the assumption that grouping depends only on the competition of similarities of achromatic colours in stimuli composed of three squares can explain the effect of number of squares. That is, mean $P_{A,B}$ should have been higher in stimuli with two squares than in stimuli with three squares, because in stimuli with three squares the similarity of the achromatic colours of B and C tended to determine the grouping of B and C at the same time when the similarity of the achromatic colours of A and B tended to determine the grouping of A and B. Accordingly, mean $P_{A,B}$ was higher in stimuli with two squares than in stimuli with three squares. Similarly, mean $P_{B,C}$ should have been higher in stimuli with two squares than in stimuli with three squares, because in stimuli with three squares the similarity of the achromatic colours of A and B tended to determine the grouping of A and B at the same time when the similarity of the achromatic colours of B and C tended to determine the grouping of B and C. Accordingly, also mean $P_{B,C}$ was higher in stimuli with two squares than in stimuli with three squares.

4 Grouping by distance

Figure 1b shows two rows of disks. In each row, subjects tend to report that the central disk groups perceptually with the left disk (Attneave and Block 1973; Bell and Bevan 1963; Oyama 1961). Is this grouping determined by absolute distance (distance between two disks), by relative distance (ratio of the distance between two disks to the longest distance between two disks), or by both of these distances?

The possibility that absolute distance determines grouping is suggested by the following finding. Prytulak and Brodie (1975) had subjects look at crosses with arms composed of equally spaced dots. The central dot of each dotted cross coincided with one dot of the arms. For each cross, subjects reported which were the arms the central dot grouped with. For fixed lengths of the arms, the proportion of reports that the central dot grouped with the dots of one arm increased with the density of dots in such an arm. This finding suggests that the probability of dots forming a group increased as the absolute distance between dots decreased. This possibility is also suggested by the following finding. Parallel lines made up of equally spaced dots may produce subjective contours (Kanizsa 1979). The clarity of these contours has been found to increase with the density of dots in such lines (Zucker and Davis 1988). This result
could indicate that the probability of perceiving a subjective contour increases with
the density of dots because the probability of dots forming a group increases as the
absolute distance between contiguous dots decreases.\(^{(1)}\)

The possibility that absolute distance determines perceptual grouping is further
indicated by the following data obtained by Pomerantz and Schwaitzberg (1975). Pomer-
antz and Garner (1973) found that the orientation of two round brackets affected
the probability of the round brackets grouping in a perceptual pair (see also Beck
1966). These authors used the four pairs of round brackets shown in figure 6a. Sequences
of pairs of round brackets were presented with each pair shown one at a time. For each
pair, subjects reported whether one of the round brackets—let us say the left-hand round
bracket—curved to the left or to the right. When the right-hand round bracket varied
unpredictably in direction of curvature, speed and accuracy of subject’s performance
were reduced with respect to when the right-hand round bracket always had the same
curvature in all pairs of a sequence. The right-hand round bracket may be called a
distractor. When the experiment was repeated with the stimuli shown in figure 6b,
with the distractor rotated 90°, the distractor no longer affected subject’s performance.
Since the distractor differed in orientation in the two experiments, Pomerantz and
Garner’s (1973) findings suggest that, owing to the proper orientation, two contiguous
round brackets tend to group more probably in figure 6a than in figure 6b. Pomerantz
and Schwaitzberg (1975) repeated the Pomerantz and Garner (1973) experiment using
the pairs of round brackets shown in figure 6a but now with the distractor set at differ-
ent distances from the left-hand round bracket. Two of these different distances are
exemplified in figure 6c for one kind of pair of round brackets. The results show that
the effect of the distractor decreased as the spacing between the round brackets of a
pair increased. This finding suggests that the probability of two elements grouping
perceptually decreases as the absolute distance between the two elements increases.

\[
\begin{array}{c}
( \ ) \\
(a)
\end{array}
\]

\[
\begin{array}{c}
( \sim ) \\
(b)
\end{array}
\]

\[
\begin{array}{c}
( ( ) ) \\
(c)
\end{array}
\]

Figure 6. Pairs of round brackets used by Pomerantz and Garner (1973), and by
Pomerantz and Schwaitzberg (1975) to study grouping.

On the other hand, the possibility that relative distance determines grouping is
suggested by the finding that, in lattices composed of dots, the probabilities of dots
forming various groupings decreases with the distance of dots from one another relative
to the size of the lattice (Kubovy and Wagemans 1995).\(^{(2)}\) This finding agrees with
Koffka’s (1935, page 164) idea that “proximity is a relative term [in that] one and the

\(^{(1)}\) In lattices composed of dots, Kubovy et al (1998) found that density of dots did not affect the
probabilities of occurrence of various groupings of dots in the lattices. However, consider that in
this study absolute distances varied within a small range and that lattices may involve processes of
textural segmentation that could differ from processes of grouping (Beck 1982; Ben-Av and Sagi
1995; Mack et al 1992). It cannot also be excluded that rules for grouping of dots differ from rules

\(^{(2)}\) In the above study of Prytulak and Brodie (1975), the probability of the central dot grouping
with the dots of an arm of a dotted cross increased with the length of such an arm. However,
when the central dot was the common end dot of two collinear dotted lines, the probability of the
common dot grouping with a line increased with the density of dots but not with the length of
the line. In dotted crosses, whether arm length affected grouping of the central dot with other dots
is unclear, because grouping could have resulted from the perceptual stratification of arms which
depends on arm length (Shipley and Kellman 1992).
same distance which in one pattern may be an intramembral distance may in another
be an intermembral one”. For example, in figure 1b the absolute distance between
the central and left disks in the top row is equal to the absolute distance between the
central and right disks in the bottom row. Since the central and left disks in the top
row and the central and right disks in the bottom row are separated by the same
absolute distance, and since the central and left disks tend to group in the top row
but the central and right disks tend not to group in the bottom row, it may appear
that the absolute distances separating these disks do not determine grouping. However,
in patterns such as those in figure 1b, the effects of absolute and relative distance are
confounded. In fact, in this figure, the distance between the central and left disks of
a row of disks is, at the same time, the shorter distance and the shortest possible
distance between two disks of such a row.

The following experiment was designed to test whether grouping was determined by
absolute distance, by relative distance, or by both of these distances. Stimuli composed
of two disks and stimuli composed of three disks were used. In stimuli composed of two
disks, only absolute distance was possible. In stimuli composed of three disks, relative
distance was also possible. It was expected that different probabilities of identical pairs
of disks grouping in these stimuli would reveal the possible effect of relative distance.

5 Experiment 3
5.1 Method
5.1.1 Subjects. Subjects were seventeen university students with normal or corrected-to-
normal vision. None of them took part in experiments 1 or 2.

5.1.2 Stimuli. The apparatus and the viewing distance were the same as those in experi-
ment 1. Stimuli were either two or three horizontally aligned disks with diameter of
1.5 mm. Figures 2d–2f show the stimuli with X, Y, and Z denoting the respective
disks. The luminance for each disk was set at 25 cd m$^{-2}$. The colour for X and Z was
white and that for Y was red. There were three kinds of stimuli: with X, Y, and Z as
in figure 2d; with only X and Y as in figure 2e; or with only Y and Z as in figure 2f.
For each stimulus, the positions of X and Z were fixed on the screen with the point
in the middle of X and Z coinciding with the centre of the screen. The distance
between the inner ends of X and Z was 52 mm. The distances between the inner ends
of Y and X and of Y and Z are represented in figure 7 on the horizontal axes of the
left and right diagrams, respectively. Negative distances represent positions of Y on
the side of X or of Z opposite to the side where there was Z or X, respectively. There
were 63 stimuli (21 different positions of Y for each of the three different kinds of
stimulus). These stimuli were duplicated and rotated 180°. The series of the resulting
126 stimuli was shown once with stimuli in random order. Stimuli were displayed as
follows. One 0.2 s warning sound was produced 1.5 s before the onset of the stimulus.
The stimulus was visible until the experimenter typed the subject’s response or until
1 s had passed from the onset of the stimulus. The subsequent warning sound was
produced 1 s after the experimenter typed the subject’s response.

5.1.3 Procedure. Before the instructions, each subject was shown on the display screen
a 9×9 rectangular matrix of blue circles each with diameter of 6 mm. In figure 3c,
filled circles represent the blue circles. The width of the gap between two contiguous
columns was 4 mm and that between two contiguous rows was 1 mm. As shown in
figure 3c, an arrow indicated the circle in row 1 and column 6. Each subject concurred
that this circle formed column 6. Subsequently, the width of the gap between two
 contiguous columns was decreased to 1 mm and that between two contiguous rows
was increased to 4 mm, thus producing a matrix with shorter distance between columns
as in the matrix illustrated in figure 3d. Each subject concurred that now the circle in row 1 and column 6, still indicated by an arrow, formed row 1.

After having verbally described the stimuli, the experimenter read the following instructions to the subject: “When you hear the warning sound focus on the centre of the screen and, as soon as the stimulus appears, say whether or not you have the impression that the red disk forms a group. If you have such an impression say which are the disks that appear to form a group.” So that subjects did not worry about their response frequencies the following sentence was also read: “The number of cases in which the red disk forms a group is predetermined randomly by the computer. The red disk could appear to form a group in many cases or in few cases or, even, in all cases or in no case.”

5.2 Results and discussion

The scores for each subject were the following: for each stimulus composed only of X and Y, the proportion $P$ of subject’s reports that Y grouped with X; for each stimulus composed only of Y and Z, the proportion $P$ of subject’s reports that Y grouped with Z; and for each stimulus composed of three disks, both the proportion $P$ of subject’s reports that Y grouped with X, and the proportion $P$ of subject’s reports that Y grouped with Z.

In figure 7, the left diagram shows mean $P$ for the grouping of Y with X, and the right diagram shows mean $P$ for the grouping of Y with Z, as a function of the distances between the inner ends of Y and X and of Y and Z, respectively. (Recall that negative distances represent positions of Y on the side of X or of Z opposite to the side where there was Z or X, respectively.) Empty triangles and filled squares show these means for stimuli composed of two and of three disks, respectively.

![Figure 7](image_url)

**Figure 7.** Results of experiment 3. With reference to figures 2d to 2f, the left diagram shows the mean proportion $P$ of reports that X grouped with Y, and the right diagram shows the mean proportion $P$ of reports that Y grouped with Z, as a function of the distance of Y from X or Z, respectively. Negative distances represent positions of Y on the side of X or of Z opposite to the side where there was Z or X, respectively. The parameter is the number of squares in the stimulus.

In stimuli composed of two disks, these results show that absolute distance determined grouping.

For levels of factors with variances higher than zero, a 2 (number of disks) by 8 (distance of Y from X) ANOVA showed that the effect of number of disks and the interaction were significant ($F_{1,16} = 12.8$ and $F_{7,112} = 4.0$, $p < 0.005$, respectively), and a 2 (number of disks) by 10 (distance of Y from Z) ANOVA showed that the effect of number of disks was significant ($F_{1,16} = 11.8$, $p < 0.005$) while the interaction was not significant ($F_{8,144} = 1.2$).
These results show that two disks group more probably when a third disk is present than when no other disk is present.

In stimuli composed of three disks, one could expect that the left and right disks compete for grouping with the central disk owing to their absolute distance from the central disk. This competition would make mean $P$ higher in stimuli with two disks than in stimuli with three disks. Instead, the results in figure 7 show that mean $P$ was higher in stimuli with three disks than in stimuli with two disks. Consequently, the present results indicate that also relative distance determines grouping.

6 Experiment 4

Thus, the present results indicate that both absolute and relative distance determine grouping. The following findings suggest that a third kind of distance could determine grouping. Suppose that two separate collinear rods are suspended in midair by a proper apparatus and slowly rotated in depth near a screen with respect to which the rods are oblique. With proper illumination of the rods by a beam of parallel light rays, the shadows of the rods cast on the screen are two collinear lines separated by a gap. When the rods rotate in depth, the lengths of the lines and the width of the gap between the lines constantly change. Illusorily, also these projected lines appear to rotate in depth (Metzger 1975). During this rotation, the lines appear either to form a rigid group or to slide in opposite directions (Gillam and Grant 1984; see also Gillam 1981, 1992). The probability of the lines forming a group increases as the ratio of the distance between the inner ends of the lines (that is, the ends delimiting the gap) to the distance between the outer ends of the lines decreases (Gillam and Grant 1984). We may call this ratio the Gillam distance.

It is possible that the Gillam distance determines grouping in stationary patterns. The following experiment was designed to test this possibility. Figure 8 shows the stimuli used for the test. In figure 8a, $d$ denotes the absolute distance between the inner ends of the two disks of each stimulus, and $D$ denotes the absolute distance between the outer ends of these disks. In passing from figure 8a to figure 8c, the ratio $d/D$—the Gillam distance—progressively approaches unity. It may be predicted that for each $d$ the probability of the disks grouping perceptually increases with the diameter of the disks because the Gillam distance decreases as the diameter of the disks increases.

6.1 Method

6.1.1 Subjects. Subjects were fifteen university students with normal or corrected-to-normal vision. None of them took part in experiments 1–3.

6.1.2 Stimuli. The apparatus and the viewing distance were the same as those in experiment 1. As exemplified in figure 8, stimuli were two horizontally aligned disks presented in the middle of the screen. The diameter of the disks was 0.5, 10, or 65 mm. For each of these sizes, $d$ varied in steps of 6 mm with the shortest $d$ being 0.5 mm.

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(3) For example, mean $P$ for X and Y would be higher in stimuli with two disks than in stimuli with three disks, because in stimuli with three disks the absolute distance between Y and Z would tend to determine the grouping of Y and Z at the same time when the absolute distance between X and Y would tend to determine the grouping of X and Y.

(4) Zucker and Davis (1988) found that the clarity of subjective contours produced by dotted lines increased with dot size (diameters of dots were quite small: either 0.8 min of arc or 1.6 min of arc). This finding suggests that dot size could have affected the probability of dots forming a group, in the sense that the increase in the clarity of subjective contours with dot size indicated that dotted lines increasingly looked unitary as dot size increased. However, since the clarity of subjective contours produced by solid lines increases with line width for widths comparable to the above sizes of dots (Lesher and Mingolla 1993), sizes of dots in Zucker and Davis’s (1988) study could have affected the probability of occurrence of subjective contours rather than the probability of dots forming groups.
and the longest 120.5 mm, for a total of 21 different values of $d$. Thus, there were 63 stimuli. These stimuli were duplicated. The resulting series of 126 stimuli was shown once with stimuli in random order. Stimuli were displayed in the same way as in experiment 3.

6.1.3 Procedure. The procedure was the same as that in experiment 3 except for the following changes in the instructions read to the subject: “When you hear the warning sound focus on the centre of the screen and, as soon as the stimulus appears, say whether you have the impression that the disks form a group or whether you have the impression that the disks are isolated from one another.” So that subjects did not worry about their response frequencies the following sentence was also read: “The number of cases in which the disks appear to form a group or appear to be two isolated disks is predetermined randomly by the computer. The disks could appear to form a group or to be two isolated disks in many cases or in few cases or, even, in all cases or in no case.”

6.2 Results
For each stimulus, the score for each subject was the proportion $P$ of the subject’s reports that the two disks formed a group. Figure 9 shows mean $P$ as a function of $d$. The parameter is the diameter of disks.

For distances of disks with variances different from zero, a 3 (diameter) by 9 ($d$) ANOVA showed that the effect of diameter and the interaction were significant ($F_{2,28} = 32.0$ and $F_{16,224} = 2.3, p < 0.005$, respectively).

Since mean $P$ increased with the diameter of disks, these results confirm that the Gillam distance determines grouping in patterns composed of stationary disks.
7 Conclusion
The results of experiment 1 can be interpreted on the assumption that only similarity of achromatic colours determines perceptual grouping. The results of experiments 3 and 4 show that the absolute, relative, and Gillam distances determine perceptual grouping.

Empirical studies show that the processing time required for grouping by distance is shorter than that required for grouping by similarity (Ben-Av and Sagi 1995; Han et al 1999a, 1999b; Quinlan and Wilton 1998). This finding implies that grouping by distance and grouping by similarity involve different algorithms or mechanisms. The present study further confirms this implication showing that grouping by distance and grouping by similarity of achromatic colours differ in number of quantitative relations—the absolute, relative, and Gillam distances versus the similarity of achromatic colours—that algorithms or mechanisms must estimate. The present results further show that the single factor of grouping by distance depends on multiple algorithms or mechanisms. In fact, since this factor involves the estimation of three kinds of distances that differ computationally, the underlying algorithms or mechanisms must also differ.

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