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Texture laciness: the texture equivalent of transparency?

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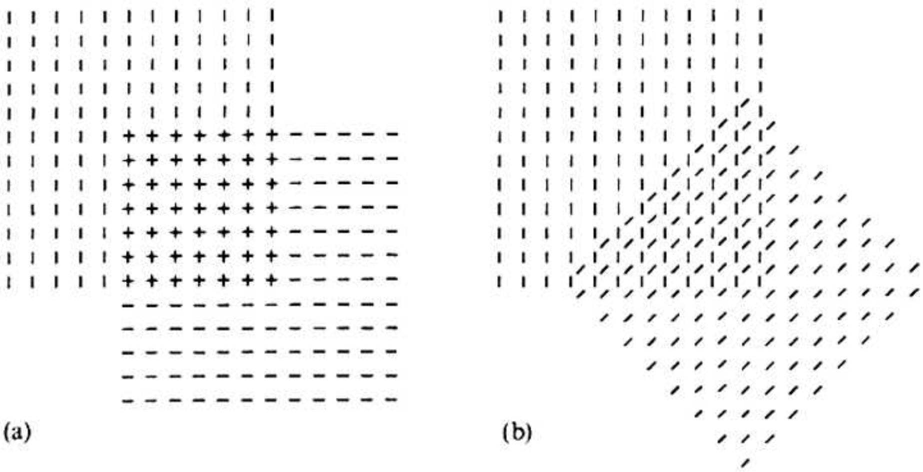
Abstract. Displays with overlapping squares of different textures were produced. In some texture combinations, the overlapping area appears to be a new texture. In other combinations, however, one texture is seen through the other as if it were inscribed on a transparent sheet and held in front of the other. This phenomenon can be called texture laciness. It is claimed that texture laciness is important because in the natural world we frequently encounter overlapping textures that we perceive as separate. In examining the conditions that lead to texture laciness, it was found that (1) laciness occurs more strongly with decreasing similarity between elements of two textures, (2) when the elements of the two textures are the same, the overlapped area tends to appear as a new texture, and (3) the physical overlapping of the individual elements of two textures hinders texture decomposition, irrespective of relative positioning. It is suggested that the textures inducing laciness may be processed as surfaces rather than just collections of identical elements. Texture laciness also reveals that even if 'antitextons'—the shapes of the spaces between texture elements, which have been regarded as important in texture discrimination—are destroyed by positioning another set of texture elements in the spaces, the textures can remain sufficiently identifiable to be perceived as separate.

1 Introduction

In a forest or street, the leaves and branches of two different, sparse trees may overlap in our view but we still see the shape of each tree and we do not imagine a new third shape or tree in the region where the two overlap. We are able to decompose one texture from another even if parts of them are overlapped. Actually, in a natural world, we see textures overlapped whenever there are transparent or lacy structures interposed between the viewer and a background surface. Although the segmentation of adjacent textures has been extensively studied (eg Beck 1966; Julesz 1975, 1981; also see Bergen 1991 for a review), little is known about decomposition of two overlapped textures.

We have examined overlapping textures to determine when the combined textures create a new, third region and when they still appear as two distinct but overlapping textures. In figure 1a, for example, the overlapping area appears to be a new, separate texture. In figure 1b, however, we have a totally different perception. That is, instead of a composite texture emerging in the overlapped area, the two square-shaped textures are perceived to overlap each other.

This composite texture is clearly discriminable from both of its constituents that flank it to either side and yet it does not stand out as a new texture. Within the overlapped region, the elements from each texture group with their appropriate pattern on either side. The two overlapping textures appear to be in slightly different depth planes. Sometimes one texture appears to be in front of the other; at other times the other appears to be in front. We call this phenomenon 'texture laciness' because one texture is seen through the other. We have examined some of the rules that govern the occurrence of texture laciness.



(a) (b)

Figure 1. Examples of two overlapped textures. (a) The combined textures create a new region. As a result, we perceive three distinctive texture regions; the upper 'L' shape consisting of vertical line elements, the central square consisting of '+' elements, and the lower 'L' shape consisting of horizontal lines. (b) The two square textures appear to be overlapped. Within the overlapped region, the elements from each texture group with their appropriate pattern on either side. We call this phenomenon 'texture laciness' because one texture is seen through the other.

2 The effect of dissimilarity of texture elements

It has been suggested that dissimilarity between groups of different elements (Beck 1966) or dissimilarity between local contrast of elements (Nothdurft 1992) determines grouping. The grouping of the texture elements within the overlapped region should also play a role and we examined this by varying the dissimilarity of the elements of the two textures in two experiments.

2.1 *Experiment 1: The effect of dissimilarity in width. Method*

2.1.1 *Subjects.* Three females and two males participated in the experiment. They were all naive to the experimental purpose. They had normal or corrected-to-normal vision.

2.1.2 Stimulus. The stimuli were presented on a color video display (Apple M0401, 640 pixel × 480 pixel resolution) controlled by a Macintosh IIci and viewed at a distance of 57.3 cm. The width and height of the display were 23.0 deg × 17.25 deg. The computer also recorded subjects' responses. Two square textures made of line elements were made to be overlapped as shown in figure 2. The width and height of each texture square were 4.6 deg. The height and width of the overlapping area were 2.5 deg. The height and width of the elements of the top texture square were 12 min and 2.4 min, respectively. Although the height of the elements of the bottom texture square was the same as that of the top square, the width was varied from 2.4 to 9.4 min in four steps.

2.1.3 Procedure. Before the start of the experiment, each subject was shown figures 3a and 3b. They were asked to give a rating of 10 when both surrounding textures seem to continue into the central square as in figure 3a and a rating of 0 when the central square seems to be a different texture from the two surrounding it as in figure 3b. There was no time restriction for the subject to respond (but all the subjects tended to respond within 10 s). They typed the rating on the keyboard connected to the computer. The same figure was presented twenty times. Thus, a whole experiment consisted of 4 (width differences) × 20 (repetition) = 80 trials. The order of the presentation of the figures was pseudorandomly determined.

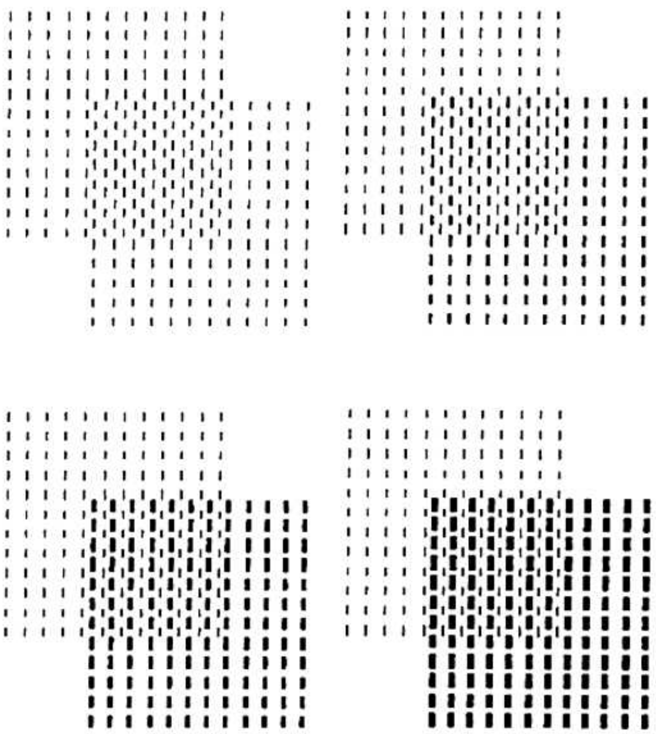


Figure 2. Stimuli used in experiment 1 in which the width of texture elements was varied in four steps.

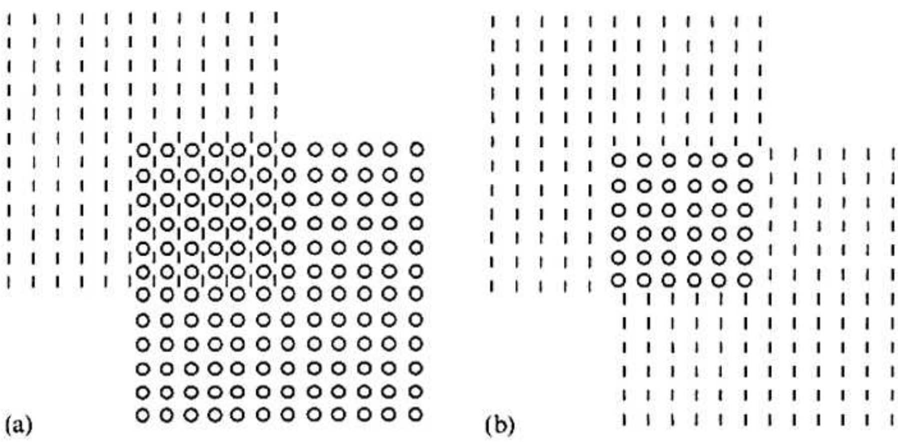


Figure 3. Figures that were shown to the subjects as the criteria for rating. The subjects were instructed to give a rating of 10 when both surrounding textures seem to continue into the central square as in (a) and a rating of 0 when the central square seems to be a different texture from the two surrounding it as in (b).

2.1.4 *Results.* As shown in figure 4, texture laciness became more salient with the increasing difference in width between the elements of the two textures. The result of one-way ANOVA showed that width difference was significant ($F_{3,12} = 41.53$, $p < 0.01$).

2.2 *Experiment 2: The effect of dissimilarity in orientation. Method*

2.2.1 *Subjects.* The five subjects who served in experiment 1 also participated in this experiment.

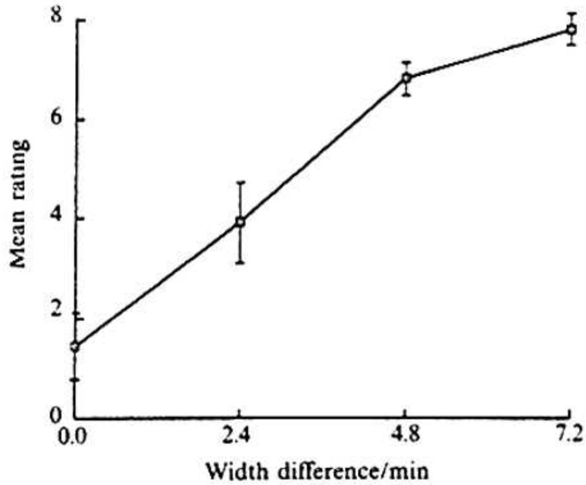
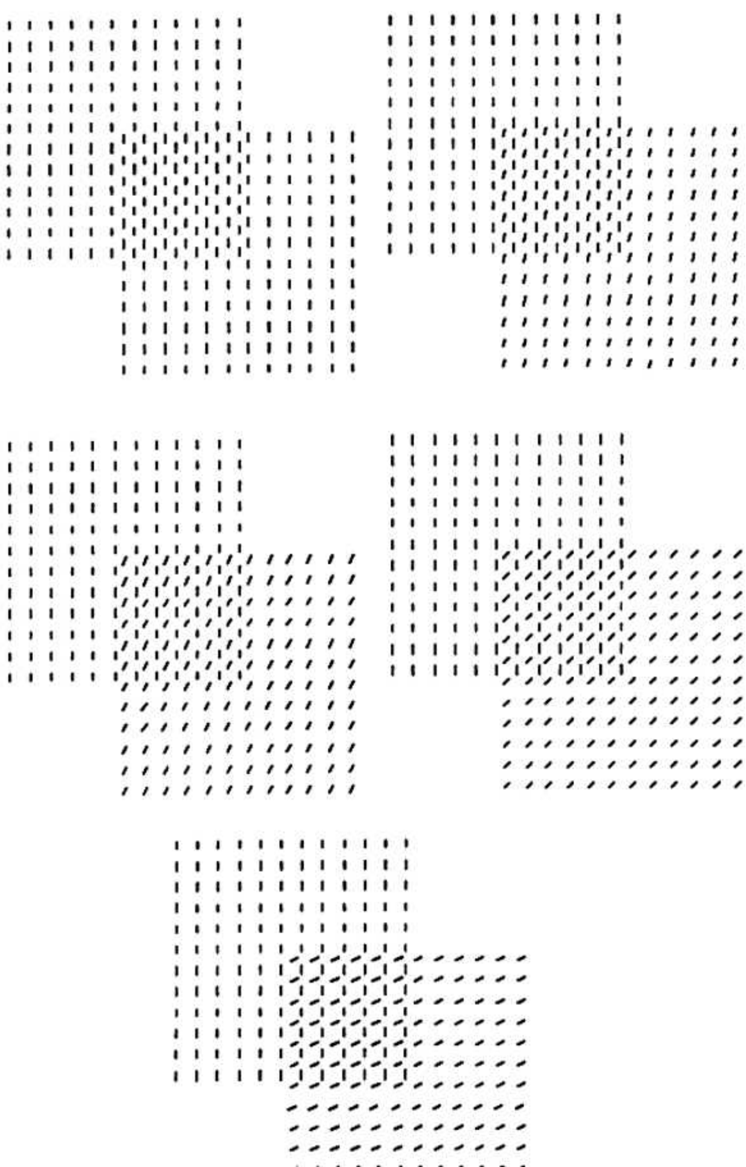


Figure 4. The mean rating for texture laciness ($n = 5$) as a function of the width difference of the elements of two textures. The rating increased with the increasing difference in width.



2.2.2 *Stimulus and procedure.* The effect of orientation difference between the elements from the two textures was examined. The orientation of the elements of the bottom texture was varied from 0° to 60° in five steps (figure 5). Each stimulus was presented twenty times. Thus, the total number of trials was one hundred. The other aspects of this experiment were identical to those in experiment 1.

2.2.3 *Results*

It can be seen from figure 6 that texture laciness became more salient with the increasing orientation difference. The result of one-way ANOVA showed that orientation difference was significant ($F_{4,16} = 19.55$, $p < 0.01$).

The results of the two experiments show that the dissimilarity between elements of two textures influences the salience of texture laciness. This further shows that the grouping of the texture elements within the overlapped region plays a role for texture laciness.

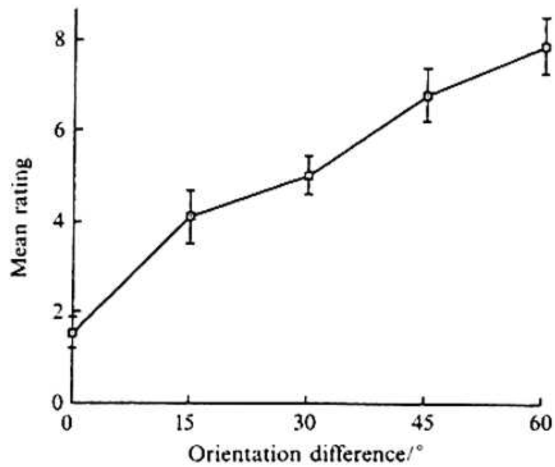


Figure 6. The mean rating for texture laciness ($n = 5$) as a function of the orientation difference of the elements of two textures. The rating generally increased with the increasing difference in orientation.

3 Experiment 3: The effect of texture offsets

We next examined the relative positioning of the texture elements, keeping both textures as regular arrays with the same spacings.

3.1 *Method*

3.1.1 *Subjects.* Two females and two males participated in the experiment. One male was one of the authors (TW). The remaining three subjects were naive to the experimental purpose. None of the subjects participated in the previous two experiments. They had normal or corrected-to-normal vision.

3.1.2 *Stimuli and procedure.* Figure 7 shows figures used in this experiment. In figures 7a–7c, identical textures were overlapped but the relative position of the texture elements were varied — the elements in the overlapped area were collinearly (figure 7a), diagonally (figure 7b), or vertically (figure 7c) aligned. In figure 7d, on the other hand, the elements of the two textures had different orientations. This figure was used for catch trials. Each stimulus was presented twenty times. Thus, the total number of trials was eighty. The other aspects of this experiment were identical to those in experiment 1.

3.2 *Results*

Figure 8 shows the results. The result of one-way ANOVA showed that the main factor [position (or orientation)] was significant ($F_{3,9} = 111.95$, $p < 0.01$). The mean rating of the texture laciness was much higher for the stimulus shown in figure 7d,

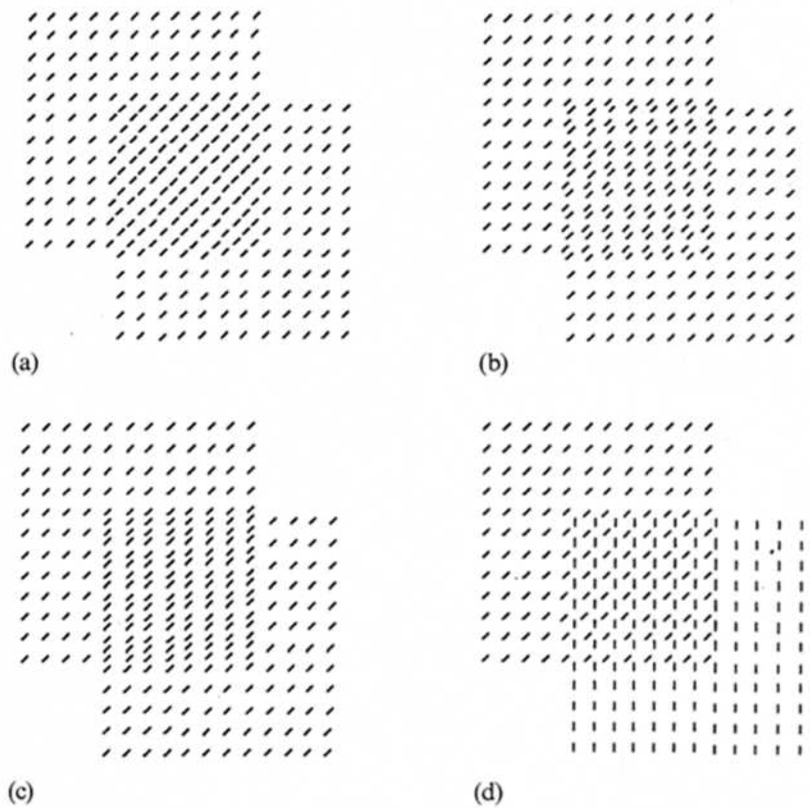


Figure 7. Stimuli used in experiment 3(a) – (c). Identical textures partially overlapped. The elements of the two identical textures are aligned (a) collinearly, (b) diagonally, or (c) vertically. (d) The elements from the two textures have different orientations.

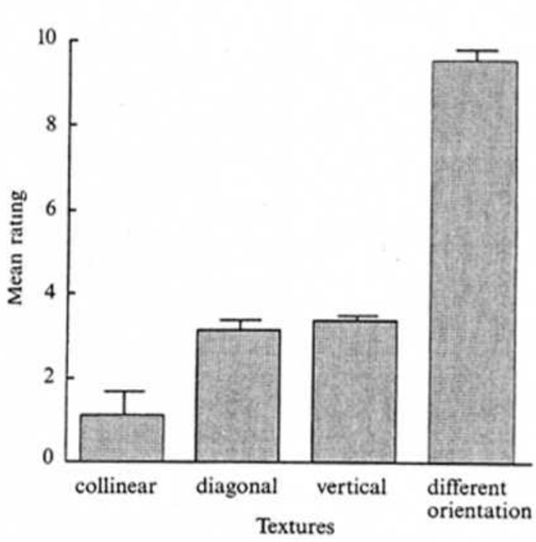


Figure 8. The mean rating of the texture laciness ($n = 4$) for the four pairs of the partially overlapped textures shown in figure 7.

where the elements of the two textures were different in orientation, than in figures 7a, 7b, and 7c, in each of which the elements of the two textures were of the same orientation. A posteriori Tukey HSD tests showed significant differences of the texture pair with orientation difference (figure 7d) from the texture pair with collinear elements (figure 7a) ($p < 0.01$), from the texture pair with diagonally positioned elements (figure 7b) ($p < 0.01$), and from the texture pair with vertically aligned elements (figure 7c) ($p < 0.01$). The mean ratings for these three pairs of textures with the same orientation (figures 7a, 7b, and 7c) were less than 4. On the other hand, there were differences found between the three pairs. The mean rating was significantly lower with the texture with collinear elements than for the textures with diagonally positioned elements ($p < 0.05$) and the textures with vertically aligned elements ($p < 0.01$).

These results suggest that when the elements of the two textures are of the same orientation, the overlapped area seems to appear as a new texture no matter what the relative positioning. In addition, when the same texture elements were aligned as in figure 7a, the tendency to make a new texture becomes even stronger (eg Nothdurft 1992).

4 Experiment 4: The effect of overlap and junctions of individual elements

We then examined the effect of overlap of individual elements from the two textures. One possibility is that once individual texture elements touch each other in the overlapping area, new local features average and a new texture will become discriminable from the surrounding textures. The individual texture elements can touch in two different ways: they can make small T-junctions and small X-junctions. A T-junction is typically a local signal for occlusion whereas the X-junction is a signal for transparency.[1] Thus, another possible result is that when the individual texture elements make X-junctions, texture laciness will occur.

4.1 *Method*

4.1.1 *Subjects.* The four subjects who served in experiment 3 also participated in this experiment.

4.1.2 *Stimuli and procedure.* From figure 9a to figure 9d, the horizontal location of the bottom texture was gradually shifted by 4.3 min to the right. As a result, the textures in figures 9b and 9d form T-junctions in opposite directions in the overlapped areas. The textures in figures 9a and 9e form X-junctions in the overlapped areas, although the overlapped area is larger in figure 9a than in figure 9e. On the other hand, figure 9c has spatially separate texture elements in the overlapped area. These five figures were used in this experiment. Each stimulus was presented twenty times. Thus, the total number of trials was one hundred. The other aspects of this experiment were identical to those in experiment 1.

4.2 *Results*

It can be seen from figure 10 that the rating of the texture laciness was much higher for the textures with spatially separate elements than for the textures with T-junctions and X-junctions. The result of one-way ANOVA showed that horizontal offset was significant ($F_{4,12} = 6.316$, $p < 0.01$). An a posteriori Tukey HSD test showed that the rating was significantly higher for textures with separate elements than for the textures with X-junctions (both for figure 9a and for figure 9e, $p < 0.01$) and with T-junctions (both for figure 9b and for figure 9d, $p < 0.05$).

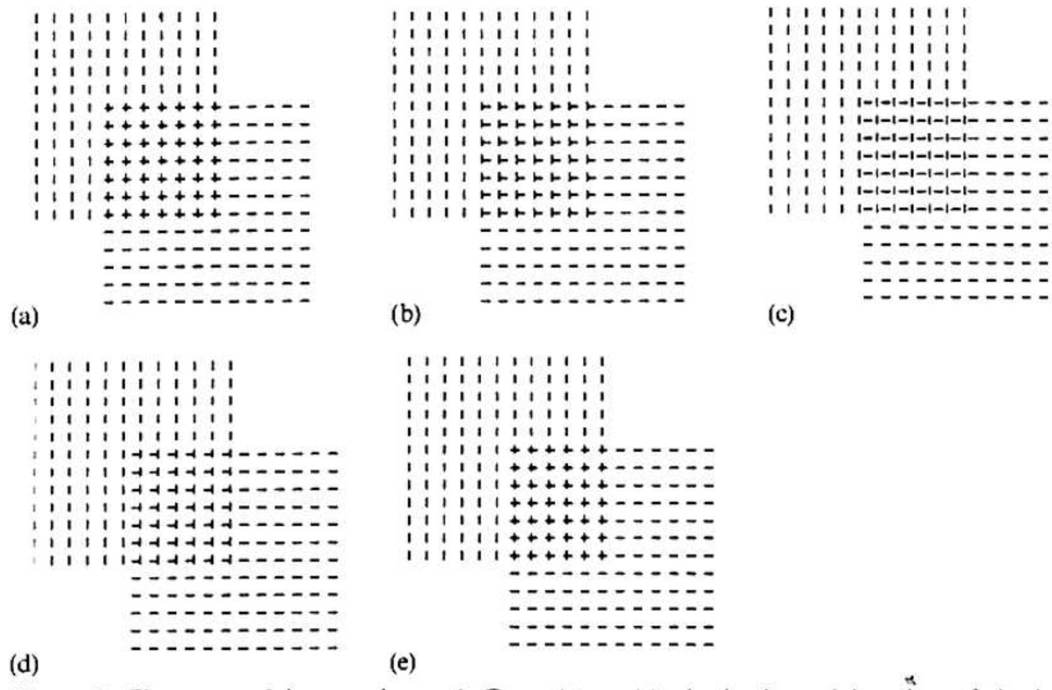


Figure 9. Figures used in experiment 4. From (a) to (e), the horizontal location of the bottom texture was gradually shifted.

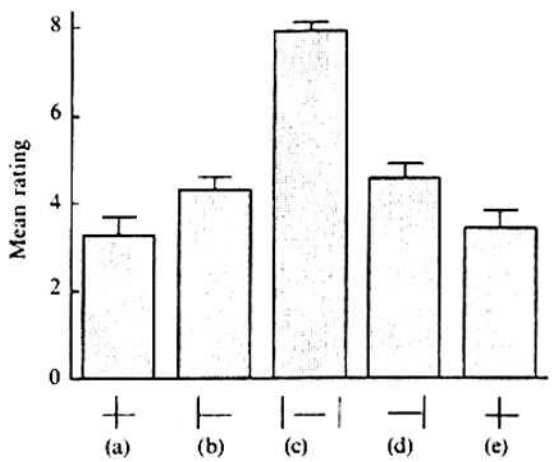


Figure 10. The mean rating of the texture laciness ($n = 4$) for the five pairs of the partially overlapped textures shown in figure 9. The elements in the overlapped areas are illustrated for each of the texture pairs; (a) – (e) indicate the part of figure 9 in which the whole stimulus is shown.

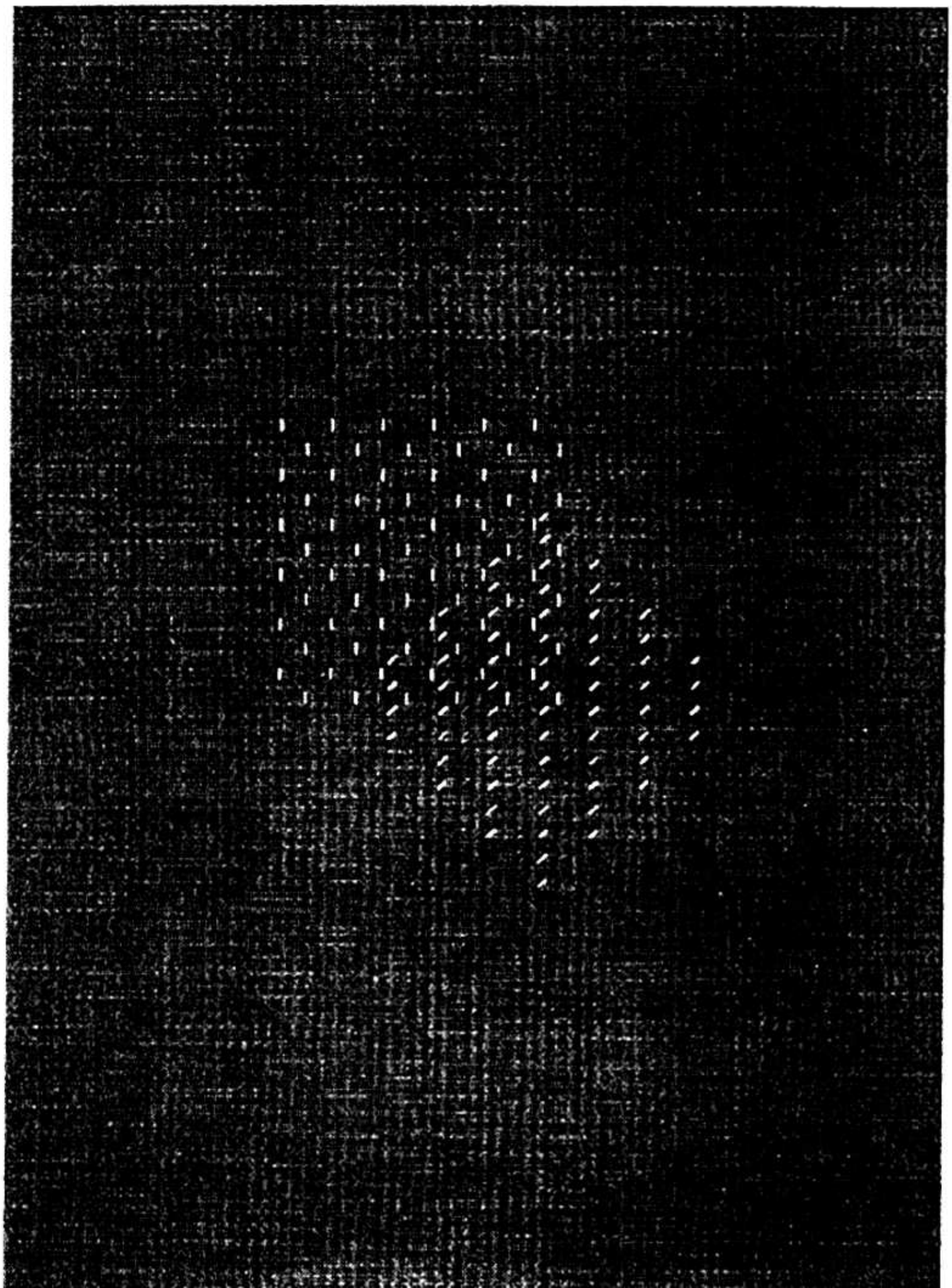
These results suggest that once texture elements are separate as in figure 9c, texture laciness occurs. However, once individual texture elements touch each other in the overlapping area as in figures 9a, 9b, 9d, and 9e, new local features tend to emerge and a new texture becomes discriminable from the surrounding textures. X-junctions made of texture elements appear to have no effect in the decomposition of the texture elements here.

5 The effect of the mean luminance of the textures

Finally we examined the influence of the mean luminance of the textures in the flanking regions and in the overlapping region to determine whether Metelli's laws of transparency (Metelli 1974; Beck et al 1984) were contributing to laciness.

In all of the examples shown for texture laciness, the average luminance in overlapping areas is lower than the average luminances of nonoverlapping areas of two textures. This means that the average luminance combination in these areas is valid for transparency. The question is whether this valid average luminance combination plays a significant role for texture laciness.

In figure 11, the average luminance value of white and black elements is set to be identical to that of the background so that average luminance of every texture area is the same. Still we see texture laciness, although it becomes slightly less salient



than in figure 1b partly because of the local grouping of black and of white elements. This indicates that luminance values which are valid for transparency are not necessary for texture laciness.

6 General discussion

In our present study we have identified some of the rules that govern when one texture is seen through another in an area where the two overlap. This texture laciness increases with the dissimilarity of the individual texture elements of the two textures and decreases with the overlap of the elements. We also found that mean luminance values do not have to follow Metelli's laws for texture laciness to occur.

The figural arrangement of overlapping squares that we used for examining texture laciness is similar to that used to test other types of transparency. Transparency of overlapping untextured squares can be seen if the regions have appropriate luminances (Beck et al 1984; Watanabe and Cavanagh 1993b). The brightness of the overlapping area is decomposed into two values, one assigned to each of the overlapping surfaces. In addition, it has been found that in the two-square overlapping configuration, the velocity of the moving random dots in the overlapping area is decomposed into the two component velocities that are the same as the velocities of the random dots defining the two squares and these squares appear to be overlapped transparently (Watanabe 1993, 1994). The visual system may decompose each of the features such as brightness, motion, and texture in order to match a surface representation — in the present case, a representation of two surfaces at the same location — required by figural configurations.

Texture laciness may be a function of grouping of like texture elements in the overlapping region where the two types of elements intermingle. On the other hand, it may be an indication that the texture is treated as a surface rather than just a collection of identical elements. Since two surfaces cannot occupy the same location and depth, the visual system could assign them different depths and represent one or both of them as transparent.

The occurrence of texture laciness has important consequences for models of texture discrimination. Specifically, in recent models not only have the shape and positioning of the texture elements been considered but also the shapes of the spaces between the elements (eg Williams and Julesz 1992). These 'antitextons' would be destroyed by positioning another set of texture elements in the spaces and yet, in several instances that we have shown, the textures remain sufficiently identifiable to be perceived as separate and continuous with the flanking constituent textures.

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