

Effects of partial occlusion on perceived slant difference

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When two slanted surfaces are placed in proximity, the perceived slant difference between them is exaggerated. This effect has been called slant contrast. When a partial occluder is presented in front of the gap between them, the perceived slant difference between the surfaces is reduced. We refer to this reduction in perceived slant difference as stereo-slant assimilation. We investigated two properties of the occluder that might affect perceived stereo-slant difference. Three vertically aligned random-dot patterns were presented either with a partial occluder over the gaps between them or without it. Observers judged the perceived slant difference between the center pattern and two surround random-dot patterns that had the same slant. The perceived slant difference was reduced when the partial occluder was present. We varied stereo-depth and slant of the occluder and found that the decreased perceived slant difference was not due to either of these. Note that the surfaces were all simulated and presented on a computer screen and the results may not apply to real surfaces. The effect of the occluder on perceived slant differences could have resulted from either a reduction of slant contrast or an increase of slant assimilation.

Keywords: amodal completion, perceptual grouping, partial occlusion, stereo-slant assimilation, stereo-slant contrast, stereo-slant percept

Introduction

The perceived slant of surface patches can be influenced by the slant of adjacent patches that cause the slant percept to be either exaggerated (slant contrast) or reduced (slant assimilation). For example, Gillam & Blackburn (1998) found that when a fronto-parallel surface was added above or below a slanted surface, the fronto-parallel surface appeared to be slanted away from the slanted surface, and the slant difference between the two surfaces was increased. The interactions between the two surfaces is thought to occur at a local level because the effect of adding the second surface decreased as the depth or vertical separation between the two surfaces increased. This increased slant difference is related to the stereo-slant contrast effect first described by Werner (1937). When a small fronto-parallel object is presented within a larger slanted background, the fronto-parallel patch appears slanted opposite to the background slant and the perceived background slant is reduced (Werner, 1937, 1938). Hakkinen & Nyman (1997) also showed that the slant estimate of a slanted surface was reduced by an adjacent frontal-parallel occluder compared to a no-occluder condition.

Sensitivity for stereo-depth discrimination (Yin, Kellman, & Shipley, 2000) and perceived stereo-slant differences between surface patches (Fantoni, Gerbino, & Kellman, 2004) can also be reduced, presumably by perceptual grouping. For example, Yin et al. (2000) demonstrated that the sensitivity to stereo-depth difference between two

surface patches was reduced when one of the surface patches was perceptually grouped with two flankers compared to the no-flanker condition. Fantoni et al. (2004) also found that the perceived slant difference between two vertically aligned bars was reduced when an occluder was presented in the gap between them.

Analogous spatial interactions have been described for luminance and color perception. The perceived luminance (i.e., brightness) of a surface patch can either be biased away from the surrounding luminance (luminance contrast) or towards nearby luminance (luminance assimilation) (Helson, 1963; Li & Gilchrist, 1999; van Bezold, 1876). Two related spatial interactions observed in color perception are color contrast and color assimilation (van Lier & Wagemans, 1997; Xian & Shevell, 2004). Color contrast occurs when one color is surrounded by a different color, the difference in color appears exaggerated. Color assimilation occurs when two color patches are perceptually grouped, and their apparent color difference is reduced. King (1988, 2001) hypothesized that contrast occurs when patches are perceived as separate “wholes” while assimilation resulted when the two patches are perceived as one integrated “whole.”

Similar terminology could be used for stereopsis. Slant contrast occurs when slant differences appear exaggerated and slant assimilation occurs when differences are reduced. While slant contrast and its underlying mechanisms have been investigated extensively (van Ee & Erkelens, 1996a; van Ee, Banks, & Backus, 1999), there is little known about the effect of occlusion on slant assimilation. We carried out several experiments to

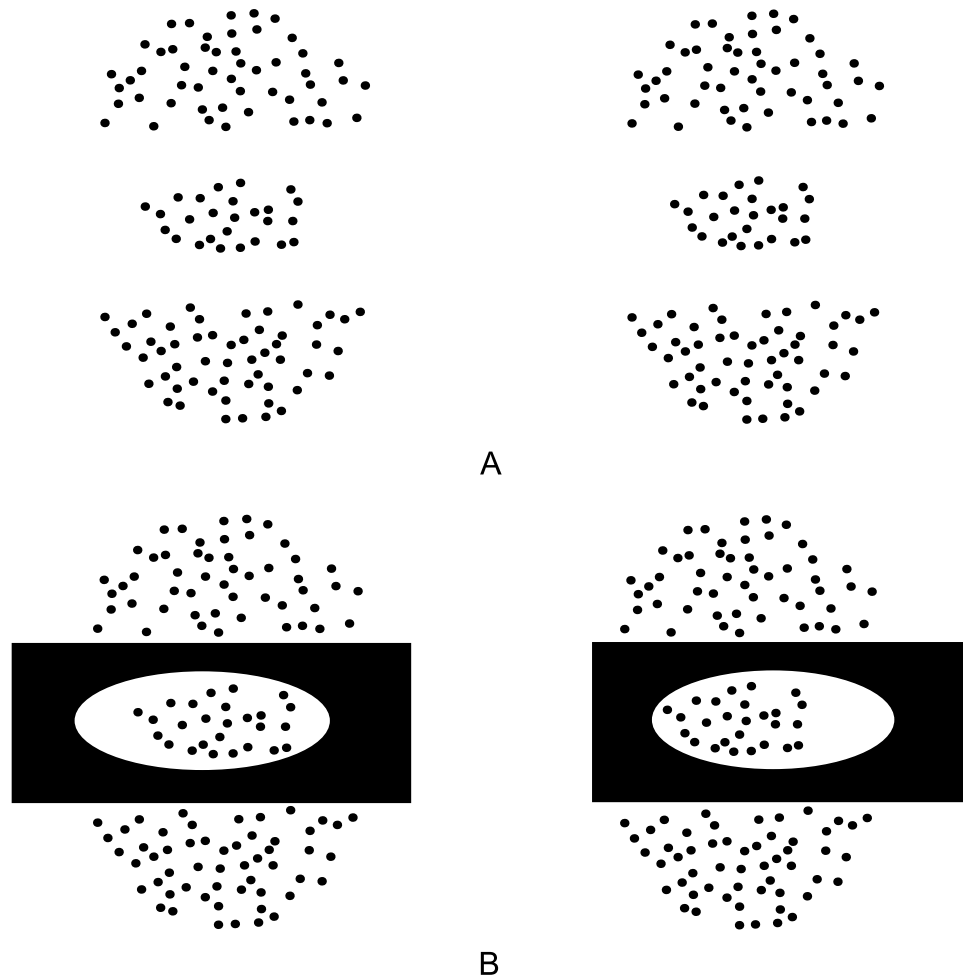


Figure 1. A demonstration of the two basic conditions in the experiments. The two images can be crossed fused for a stereo percept. (A) The three random-dot surfaces without an occluder; (B) the three surfaces with an occluder. The colors of the stimuli were reversed in this demonstration compared to the stimuli in the experiments.

investigate two spatial properties of the occluder that might affect the perceived slant difference between background surfaces. Local spatial interactions between stereo surfaces were assessed by varying the stereo-depth and the slant of the occluder relative to the other surface patches. The results of the experiments showed that the occluder decreased the perceived slant difference between the random-dot surfaces and that this effect was not influenced by either the amount of depth or slant of the occluder.

General methods

The three experiments utilized similar display technology, stimuli, subjects, and procedures. The differences for each experiment are listed under the separate experiments. In all the experiments, surface patches composed of random dots were used as stimuli. Two

hemi-circles were aligned vertically about a small oval-elliptical patch centered between them. The horizontal slant of the surrounding hemi-circles was the same and the slant of the center ellipse was varied about a vertical axis (Figure 1). Subjects estimated the slant difference between the small central patch and the two large surrounding patches. Two main conditions were used in three experiments. In the first condition, the three random-dot surface patches were presented unoccluded. In the second condition, an opaque rectangular surface with an open-center aperture was added to occlude the spaces between the three random-dot surfaces. Under this condition, the three random-dot patterns could be perceived as a single, partially occluded, surface.

Display and stimuli

Stimuli were presented on a 20-in. monochrome monitor (Monoray Model M20ECD5RE; Clinton Electronics, IL, USA) at 120 Hz non-interlaced frame rate

with 1024×768 -pixel resolution. Video images were controlled by using Visual Stimulus Generators (VSG) 2/4 graphics card (Cambridge Research Systems, Kent, England) in a host Pentium II computer. The images were corrected for any screen distortions at the 80-cm viewing distance using a grid-loom calibration method (Backus, Banks, van Ee, & Crowell, 1999). At that viewing distance, each pixel subtended 1.5 arcmin. Subpixel resolution was obtained by anti-aliasing each dot. Stimuli were viewed through 120-Hz ferro-shutter optics (model FE-1 ferro-electric shutter goggle; Cambridge Research Systems, Kent, England). Each eye viewed stimuli at 60 Hz with no discernable flicker.

Three surface patches, composed of white random dots were shown on black background. A demonstration of the surfaces and the perceived slant difference between the central and surrounding surfaces is shown in Figure 1A. Notice that the slant difference between the three random-dot surfaces appears reduced with the partial occluder presented at a nearer distance. The two random-dot surrounding surfaces were hemi-circles with a radius of 6° . These two surfaces were aligned vertically and there was a 3° vertical gap separation between their inner boundaries. The center random-dot surface was elliptical ($9.6^\circ \times 1.8^\circ$).

Slant was produced by altering the horizontal disparity gradient to cause an apparent rotation of the surface rotating about the vertical axis. All the surfaces were rotated around the vertical axis through the center of the screen. Surface slant was generated by horizontal magnification of one eye's retinal image thereby creating horizontal size ratios (HSRs) greater or less than 1.0. Positive slant corresponds to slant generated by horizontal magnification of the left eye's retinal image ($\text{HSR} < 1.0$), which produced a surface seen with the left side farther away. Negative slant corresponds to slant generated by horizontal magnification of the right eye's retinal image ($\text{HSR} > 1.0$). The HSRs of the two surrounding surfaces were always identical. The HSR of the center patch was varied from that of the surrounding patches to produce a range of slant differences. All centers of the three surfaces were at the same distance as the display monitor screen (80 cm).

A fourth surface could be added to occlude the gaps between the three random-dot surfaces (see Figure 1B). The occluder was presented on half of the conditions. It was a $15^\circ \times 3^\circ$ opaque white rectangle. A black elliptical aperture ($10^\circ \times 1.8^\circ$) was at the center of the rectangle. The aperture was wider than the center random-dot surface patch to avoid creating unmatched dots at the edges of the random-dot pattern. The occluder had 1.0° pedestal disparity so that it appeared in front of the three surface patches. Under most conditions, the occluder had the same slant as the surrounding surface patches, taking into account the horizontal disparity pedestal of the occluder.

Conditions and procedure

The three experiments were carried out in separate sessions. Within each session, the occluder was either present or absent. The sessions with and without the occluder were run alternately. The slant difference between the base slant of the surrounding random-dot surfaces and the slant of the center patch was varied and different slant differences were presented randomly within experimental sessions. Specific conditions for the base slant and slant difference are described under each experiment.

The stimuli were presented in complete darkness to prevent features in the room, edges of the display, and facial features to act as reference frames for slant perception. The observer's head position was restricted by a bite bar and a headrest. Observers sat in the darkness for 3–5 min before running the experiments to dark adapt.

At the beginning of each session, a dot and a fixation cross were presented at the center of the screen. After the fixation cross was fused, observers pressed a button to start the experiment. Three or four surfaces (i.e., three random-dot patches with or without the occluding surface) were presented for 2 s. The stimuli then disappeared and a probe figure appeared that represented the plan view of the scene with two lines and a symbol of the head. The two lines subtended 6.9° . One of the lines was horizontal and the orientation of the other line was manipulated by the observer to "indicate" the perceived angle in depth between the two lines to the slant difference between the central patch and the two surrounding surfaces. A positive slant difference indicated the percept (in plan view) of a counter-clockwise slant of the surround surface patches (left side appears closer) relative to the center patches and a negative slant difference indicated a clockwise slant of the surround surface (right side appears closer) relative to the center. After the observer made the setting, he or she pressed a button and a new trial started with the presentation of a fixation cross for the next trial.

Experiment 1: The effect of partial occlusion on perceived slant difference

The first experiment investigated perceived slant difference between the center and surround random-dot patches when a partial occluder was in front of the gaps between them. In the experiment, perceived stereo-slant differences were compared between the center and surrounding random-dot surfaces, with and without an occluder, that had the same disparity-defined slant as the surrounding (half-circle) random-dot surfaces. The occluder was presented on a 1° crossed horizontal disparity pedestal

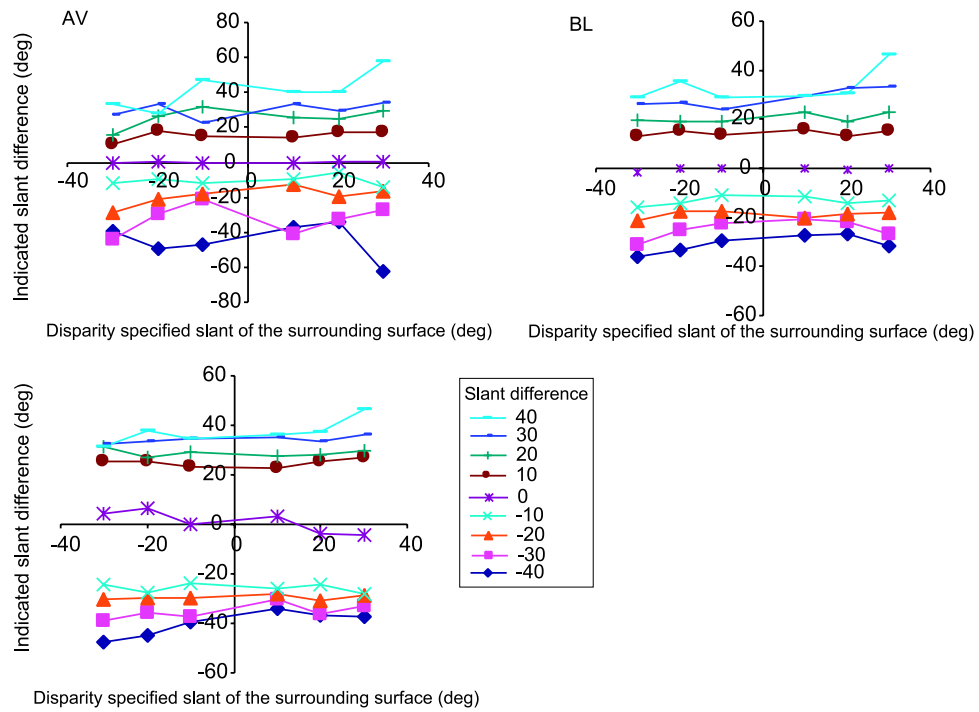


Figure 2. The indicated slant differences when the occluder was not present are plotted as a function of the base slant of the surrounding surfaces. The curves are the results for different slant differences.

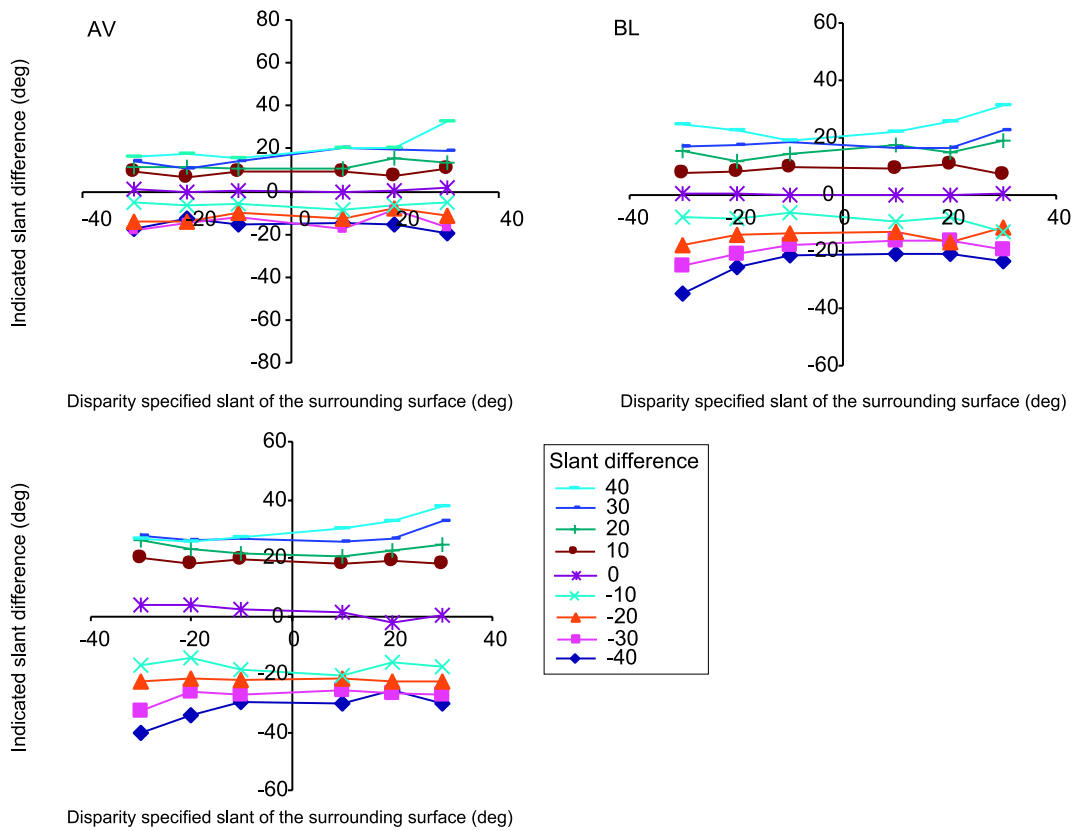


Figure 3. The indicated slant differences when the occluder was presented are plotted as a function of the base slant of the surrounding surfaces. The curves are the results for different slant differences.

in front of the random-dot patches. The perceived slant difference between the center surface patch and surrounding patches was smaller when the occluder was present than when it was absent.

Methods

Subjects

Three observers participated in the experiments (AV, BL, and DS). Two of them (AV and DS) were unaware of the experimental design and the goal of the experiments. The other was one of the authors.

Conditions

The slant difference between the center patch and the base slant of the two surrounding surface patches was selected from one of the following nine angles: -40° , -30° , -20° , -10° , 0° , 10° , 20° , 30° , and 40° . The base slant of the two surrounding surfaces (i.e., half circles) was selected from one of the six conditions: -30° , -20° , -10° , 10° , 20° , and 30° . Altogether, there were 54 different conditions based on the slant difference between the central surface and the surrounding surfaces and the base slant of the surrounding surfaces. The occluder was presented on a 1.0° horizontal disparity pedestal so that it appeared in front. It had the same slant (specified by

disparity) as the surrounding surfaces. Disparity-specified slant was computed from the horizontal disparity gradient, viewing distance and azimuth (Backus et al., 1999). The 54 conditions were presented twice within one experimental session. The order of presentations was random. Thus, each session had 108 trials. The experiment had three sessions with the occluder and three without it. For each slant difference condition (various base slants of the surrounding surfaces), there were 36 repetitions for the with- and without-occluder conditions.

Results

The same disparity-specified slant difference between the center and surrounding random-dot surfaces was presented with a range of base slants of the surrounding surfaces. It is possible that the estimates of slant difference could be influenced by the base slant of the surrounding surface patches as well as the center-surround slant difference. ANOVA analysis on all the slant difference estimates (with and without the occluder) showed a significant main effect of slant difference, $F(8,323) > 186.98$, $p < .05$. The base slant of the surrounding surface patches did not influence the results significantly, $F(5,323) < 1.70$, $p > .05$. The results of when the occluder was not presented are plotted in Figure 2. The separate curves are plots of indicated slant difference as a function of base slant. They show little effect of base slant on

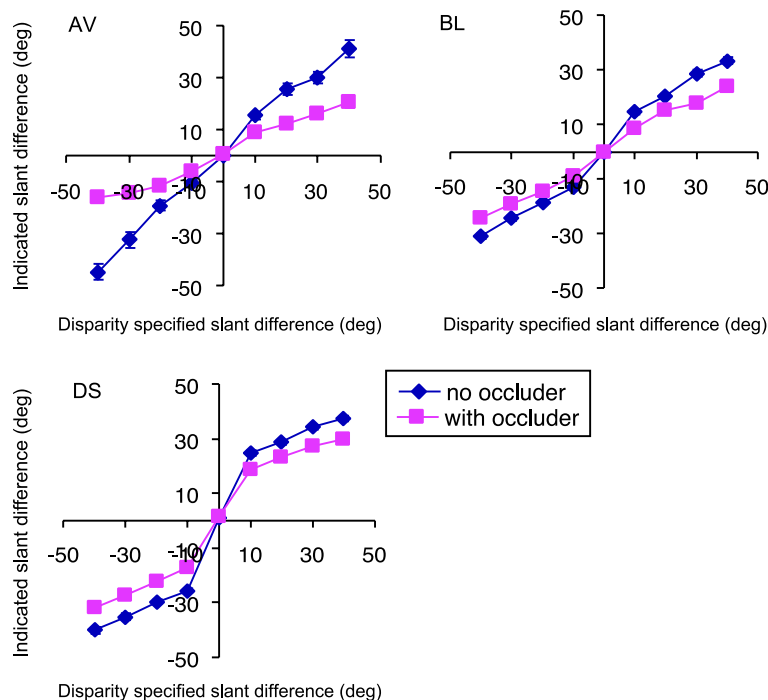


Figure 4. Indicated slant difference with and without the occluder are pooled across different base slants. The error bars are ± 1 SE of the results. For many of the conditions, the SE was too small to be visible in the figure.

perceived slant difference. The estimates of slant difference with an occluder present were also independent of base slant and these data are presented in [Figure 3](#). Notice that the horizontal curves are more compressed in [Figure 3](#) than in [Figure 2](#), illustrating that indicated slant differences were smaller with the occluder.

Because the various slant differences were presented randomly with base slant in an experimental session and the slant difference estimates mainly depended on the disparity specified slant difference between the center and surrounding random-dot surface patches, and not on base slant, the results at different base slants for each condition of slant difference were pooled and analyzed as one condition in [Figure 4](#). Estimated slant differences were significantly smaller when an occluder was presented in front of the three random-dot surfaces than when no occluder was presented, $t(70) > 2.62$, $p < .05$. The effect of the occluder was to decrease the slant difference between the central and surrounding surfaces.

The results cannot be explained by previous studies of the effects of occlusion on perceived slant of a single surface (Hakkinen & Nyman, 1997). If the occluder only reduced the slant estimates of individual surfaces, the slant difference estimates might not be changed by the occluder if it reduced perceived slant of all the random-dot patterns by a constant ratio. Even if the perceived slant of the center random-dot pattern was reduced more than the surround patterns because the occluder covered more of the center pattern's border, the influence of the occluder on the slant difference estimates would either be exaggerated or reduced depending on whether the surround pattern was slanted more or less than the center surface patch. However, the occluder reduced the perceived slant difference in both cases.

Experiment 2: Does depth of the occluder affect perceived slant difference?

[Experiment 2](#) tested possible disparity-specific spatial interactions between adjacent surfaces. It is possible that the results of [Experiment 1](#) were due to a spatial interaction between the occluding surface and adjacent surface patches such as described by Gillam & Blackburn (1998). They showed that adding a fronto-parallel surface above or below a slanted surface changed the slant percept of both surfaces so that the estimates of slant difference between the two surfaces were greater than that specified by values of HSR. However, the interaction between the surfaces was greatly reduced when the horizontal disparity pedestal separating the surface

patches in depth was increased from 0 to about 22 arcmin, suggesting the influence of local spatial interactions that were disparity specific.

In our first experiment, the disparity pedestal separation between the occluder and the random-dot patches was 1.0° . We used the horizontal disparity pedestal to minimize the spatial interactions between the occluder and other surface patches. Because the occluder had the same slant as the two surrounding random-dot surfaces, we assume that it had little or no effect on the perceived slant of the surrounding surface patches. However, the occluder may have influenced the perceived slant of the center surface patch. This interaction could have biased the slant estimate of the center surface patch either towards or away from the slant of the occluder and then reduced or exaggerated the perceived slant difference between the center and surrounding surfaces respectively compared to the no-occluder condition.

In [Experiment 2](#), the disparity pedestal between the occluder and other surface patches was varied to investigate whether there were local disparity-specific spatial interactions between the occluder and adjacent random-dot surface patches. It was assumed that if there were local spatial interactions between the occluder and other surfaces, the interaction would be stronger when the occluder was closer in depth to the surfaces than when it was farther away.

We also put the occluder at 1° uncrossed disparity pedestal relative to other surface patches to compare the results to when the occluder was put in front of the three random-dot patterns. If the influence of the occluder is only due to local interactions between the occluder and the random-dot patterns, the results should be similar when the occluder was put either in front or behind other surfaces.

Methods

Conditions

The apparatus, experimental setting, and subjects were the same as in [Experiment 1](#) except for the following. The stimuli were the same as in [Experiment 1](#), but with only five slant differences between the center and surrounding surface patches ($\pm 40^\circ$, $\pm 20^\circ$, 0°). Each of the five slant differences was presented with the six base slants ($\pm 30^\circ$, $\pm 20^\circ$, $\pm 10^\circ$) for 30 different conditions altogether. The occluder was presented in front of the random-dot surface patches with four horizontal disparity pedestals (0.5° , 0.75° , 1.25° , and 1.5°) or behind them at 1.0° uncrossed disparity pedestal. Within one experimental session, the 30 different conditions were presented twice randomly and the disparity pedestal of the occluder was fixed. Each condition of slant difference (i.e., across various slants of the surrounding surfaces) was repeated 36 times for each pedestal disparity (i.e., three experimental sessions for

each pedestal disparity condition of the occluder). There were also 36 repeats for each slant difference condition when the occluder was not presented.

Results

As in [Experiment 1](#), the slant difference estimates were pooled across various base slants of the surrounding surfaces for each condition of slant difference. [Figure 5](#) plots the indicated slant difference as a function of the disparity-specified slant difference between the center and surround random-dot surfaces. Four of the five curves represent data taken at the four disparity pedestals with the occluder present and the other curve shows the results with the occluder absent. [Figure 5](#) illustrates that when the occluding surface was present, the perceived slant difference between the center and the surrounding surfaces was significantly smaller than in the unoccluded condition, $t(70) > 2.09$, $p < .05$, independent of the magnitude of the crossed disparity pedestal between the occluder and random-dot surfaces.

As shown in [Figure 5](#), the depth separation between the occluder and the other random-dot surface patches

did not systematically influence the decreased slant difference between the central and surround surface. The results of observers AV and BL did not show a significant difference between the different crossed-disparity pedestal conditions, $F(3,719) < 1.4$, $p > .05$. For observer DS, the different disparity pedestal conditions did show a significant different effect on the perceived slant difference, $F(3,719) = 64.98$, $p = .001$. However, the perceived slant difference was reduced more for the larger depth separation of the occluder, which was opposite to the prediction based on local interactions between the occluder and the surface patches. Although any disparity-specific effects of the occluder on perceived slant difference between the random-dot surfaces were expected to increase as stereo-depth separation decreased, the results for most cases did not show any consistent change in the strength of slant reduction with the change in disparity pedestal. Thus, the effect of the occluder in perceived slant difference is not the same as the interactions described by Gillam & Blackburn (1998).

When the occluder was behind the other surface patches, there was still an effect of adding the occluder compared to the unoccluded condition for observers AV

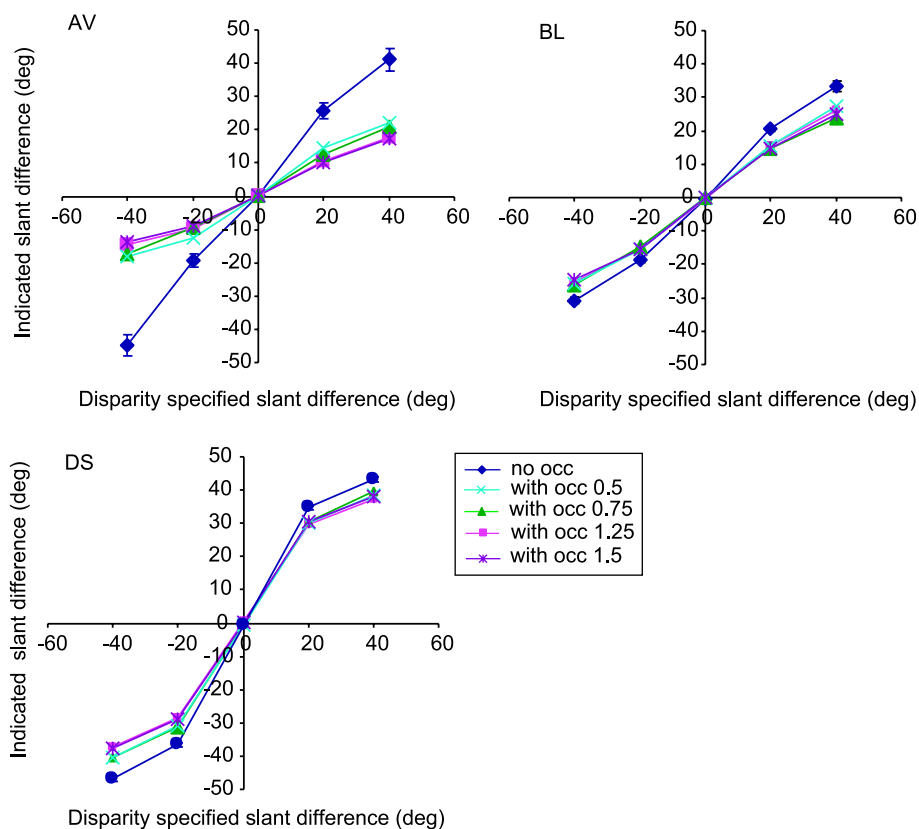


Figure 5. The results of [Experiment 2](#). The separate curves are plots of indicated slant difference plotted against disparity-specified slant difference. Different curves represent curves for different pedestal disparities (i.e., 0.5°, 0.75°, 1.25°, 1.5°) of the occluder in front of the random-dot surfaces.

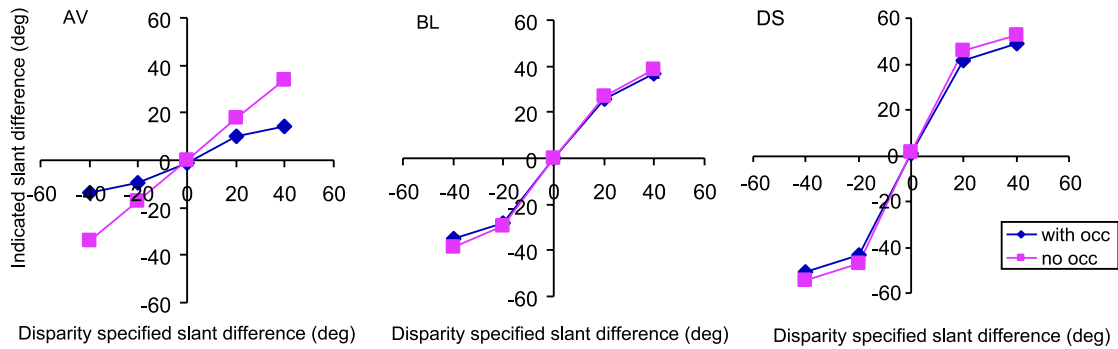


Figure 6. Indicated slant difference when the occluder was behind them as well as when the occluder was absent.

and DS, $t(70) > 2.66$, $p < .05$ (see Figure 6); however, the effect was less than for the crossed-disparity condition. For observer BL, the occluder's effect disappeared in the behind case, $t(70) = 1.73$, $p > .05$.

To compare the changes in the perceived slant difference across conditions in Experiments 1 and 2 (i.e., when the occluder was 1° in front or behind the random-dot patterns), we developed an index to compute the proportional change of indicated slant difference (CSD) with and without the occluder:

$$\text{CSD} = \frac{SD_{\text{with}}}{SD_{\text{no}}} - 1 = \frac{SD_{\text{with}} - SD_{\text{no}}}{SD_{\text{no}}} . \quad (1)$$

CSD is the proportional change in slant difference estimates, SD_{with} is the slant difference estimate when the occluder is present and SD_{no} is the slant difference estimate when the occluder is absent. If there were no difference between SD_{with} and SD_{no} , CSD would be 0; if SD_{with} were smaller than SD_{no} , CSD would be negative. A negative value in CSD demonstrates a decrease in indicated slant difference with the occluder and the magnitude of a negative CSD specifies its strength.

CSDs were computed from the results of the first and second experiment for the conditions of an occluder at the 1° pedestal disparity in the crossed and uncrossed directions. When the occluder had a 1° crossed disparity pedestal, all the CSDs were negative and significantly different from 0 ($p < .05$), demonstrating that adding the occluder significantly reduced the perceived slant difference compared to the no-occluder condition as has been shown in Figure 4. When the occluder had a 1° uncrossed disparity pedestal, most of the CSDs were still significant except three out of the four CSDs for observer BL ($p > .05$). When the CSDs were compared between the conditions of occluder at 1° disparity pedestal either in front or behind the random-dot surfaces, the CSDs were significantly reduced for the uncrossed pedestal compared to the crossed pedestal condition for observer BL and DS under seven out of eight comparisons ($p < .05$). For AV,

the CSD did not show a significant difference between the crossed and uncrossed pedestal for three out of four comparisons ($p > .05$). Under the other condition, the CSD was significantly larger when the occluder was behind than when it was in front of the random-dot surfaces ($p < .05$).

Local spatial interactions could have contributed to the decreased perceived slant difference when the occluder was placed behind the random-dot surfaces compared to the no-occluder condition. However, the significant reduction in the effect of the occluder when it was put behind the random-dot patterns compared to when it was in front of other surfaces suggested that there might be some other processes involved other than local interactions. When the occluder was put behind the random-dot patterns, it was not perceived as an occluder suggesting that the occluding relationship between the surfaces might be critical for the reduction in perceived slant differences.

Experiment 3: Does the slant of the occluder influence the perceived slant difference?

In the previous experiments, the occluder had the same slant as the surrounding surface patches. Perhaps the perceived slant of the occluder biased the perceived slant of the central random-dot pattern. This could have reduced the perceived slant difference between the center and surrounding patches.

In Experiment 3, the slant of the occluder was varied independently from the slant of the random-dot surface patches, and the slant of the center random-dot surface patch was kept at fronto-parallel. If slant of the occluder influenced the perceived slant of the center patch, it might bias slant estimates of the center patch either towards the slant of the occluder or away from it to

produce either larger or smaller slant differences from the surround. For instance, if the slant of the occluder and the surrounding surface patches have opposite sign, the slant of the center surface patch might be biased toward the slant of the occluder and the perceived slant difference between the center and surround would be larger when the occluder was present than when it was absent. If the slant of the center surface patch was biased away from the slant of the occluder, the perceived slant difference would be smaller when the occluder was present than when it was absent. Similarly, if the slant of the occluder and the surrounding surface patches have the same sign, the slant of the center surface patch might be biased toward the slant of the occluder and the perceived slant difference between the center and surround would be smaller when the occluder was present than when it was absent. If the slant of the center surface patch is biased away from the slant of the occluder, the perceived slant difference would be larger when the occluder was present than when it was absent. If the slant of the occluder affected the perceived slants of the center and surround equally, it would not influence the slant difference between them. In this case the occluder would not affect the results, and the influence of the occluder on perceived slant difference could be interpreted as resulting from another source such as a high-level perceptual grouping of the center and surround patches.

Methods

The apparatus, subjects, and procedures were the same as in [Experiment 1](#) except for the following. The surrounding surfaces had a range of six base slants ($\pm 30^\circ$, $\pm 20^\circ$, $\pm 10^\circ$). The occluder had slants of $\pm 30^\circ$, $\pm 20^\circ$, $\pm 10^\circ$, and 0° that were varied independently of the surround base slant. The center patch was always fronto-parallel (i.e., 0° slant), so the slant difference between the center and the surrounding surface patches was the same as the slant of the surrounding surfaces ($\pm 30^\circ$, $\pm 20^\circ$, $\pm 10^\circ$). All 42 combinations of slant difference and occluder slant were presented in one session and each condition was presented twice randomly within each session. There were 10 repetitions for each combination of slant difference and occluder slant (i.e., five experimental sessions).

Results

The results showed that varying the slant of the occluder did not influence the perceived slant difference between the center and surround ([Figure 7](#)). The perceived slant difference between the random-dot surfaces was significantly smaller when the occluder was presented than when it was absent, independent of the slant of the

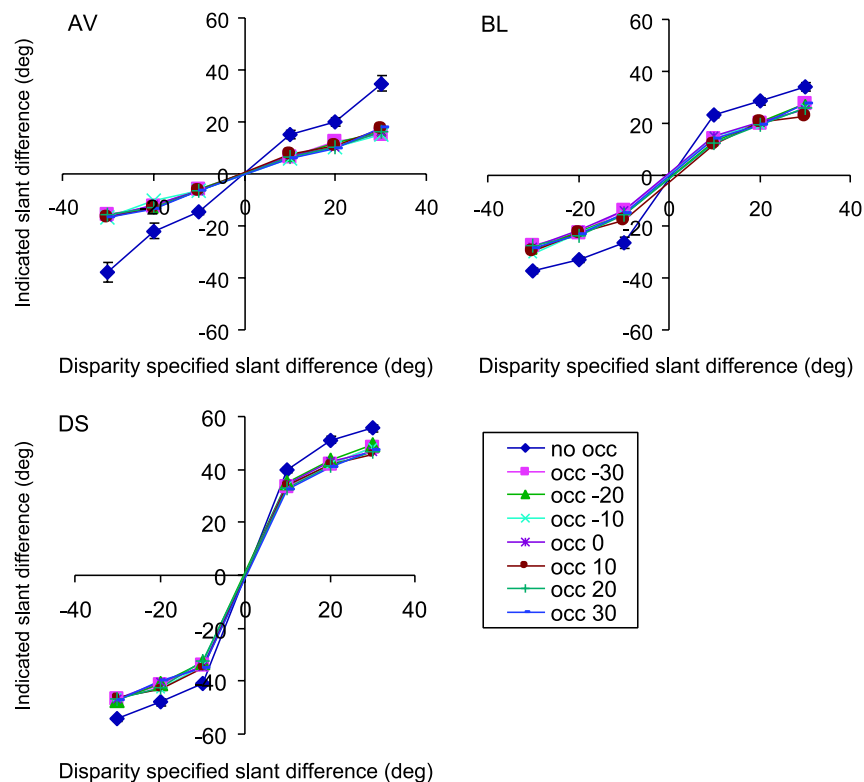


Figure 7. The results of the indicated slant difference when the slant of the occluder varied. Different curves showed the indicated slant difference when the slant of the occluder varied from -30° to 30° . The slant of the center surface was fixed at 0° .

occluder, $t(18) > 2.11$, $p < .05$. No systematic effect due to the slant angle of the occluder was found, $F(6,419) < 0.049$, $p > .05$.

Discussion

Main findings

The present study investigated the effects of an occluder on perceived slant difference between adjacent random-dot surfaces. The first experiment illustrated that an occluder reduced the perceived slant difference between adjacent random-dot surfaces. In the experiment, three random-dot patterns were either presented by themselves or with an occluder in front of them. The perceived slant difference between the three random-dot patterns was significantly reduced when the occluder was presented compared to the no-occluder condition.

Two hypotheses about how the occluder might influence perceived slant difference were tested. In the first one, disparity-specific spatial interactions between the occluder and random-dot surfaces could decrease the perceived slant difference between the center and surround. In the second hypothesis, spatial interactions between the slant of the occluder and center surface patch could bias the center slant towards or away from the slant of the surround.

[Experiment 2](#) tested the first hypothesis by varying the stereo-depth separation, produced by a crossed and uncrossed horizontal disparity pedestal between the occluder and other surfaces. No systematic trend was found that was related to the crossed-horizontal disparity pedestal between the occluder and other surface patches. However, the effect was reduced when the occluder had an uncrossed disparity suggesting that figure-ground organization might have influenced the decreased slant difference between the random-dot surfaces. In [Experiment 3](#), the second hypothesis was tested and the slant of the occluder was varied independently from other surfaces while keeping the slant of the center surface patch at fronto-parallel. No systematic effects of the occluder slant were found. The results from the two experiments suggest that decreased differences in slant of the random-dot surfaces did not result from spatial interactions between the occluder and adjacent surface patches.

In the present study, the slant difference estimates depended only on the slant difference between the surface patches and they were not influenced by the slants of individual surfaces such as the surround surface patches or the occluder. No systematic change related to the base slants of the surround surfaces was found for the same slant difference condition. In addition, when the slant of the occluder was varied independently from other surfaces

patches, no effect of the occluder slant was found on the slant difference estimates. These results indicated that the slant of the occluder and the slants of the surround and center surface patches were not critical variables for decreasing perceived slant differences, and they suggest that the effect of the occluder was mainly associated with high-level perceptual grouping.

Effects of a visual frame of reference provided by the occluder

Does the occluder reduce the perceived slant difference between the center and surround patches by weakening a disparity frame of reference for the random-dot patches? The benefit of a reference is to remove any common noise, such as caused by vergence fluctuations, and improve the signal to noise ratio of the disparity signals. [van Ee & Erkelens \(1996b\)](#) showed that a visible frame of reference increased the slant percept of a single patch, presumably because the disparity difference (relative disparities) between the reference and test patch have common noise, such as disparity introduced by vergence, and this noise is subtracted out when forming relative disparities between the reference and test patch. Without the occluder, our center and surround patches were references for one another and their relative disparity would reduce the noise of slant estimates. With the occluder, disparities of both the center and surround patches might have been referenced to the occluder edges that contain little horizontal disparity information. The upper and lower edges of the occluder could have been a weaker reference for both the center and surround than the random-dot patch disparities when the occluder was absent. Thus, when the occluder was present, disparity signals could have been noisier and caused perceived slant of both the center and surround surface patch to be smaller than when the occluder was absent. If the perceived slant of both the center and surround with the occluder was reduced proportionally compared to the unoccluded condition, then the perceived slant difference between the center and surround random-dot patterns would be less than when the occluder was absent.

The influence of relative disparities subtended by the occluder on perceived slant difference between the center and surround patches would be expected to decrease as its disparity pedestal from the random-dot patches was increased and cause greater slant differences. Our results did not verify this prediction. We would also expect reduced sensitivity to slant difference estimates measured with than without the occluder. This latter prediction was tested by comparing variances of slant difference measures with and without the occluder with an F test. When the occluder was present, we had five crossed and one uncrossed disparity pedestal conditions measured in [Experiments 1](#) and [2](#). [Table 1](#) lists the number of

	Disparity pedestal between the occluder and the random-dot patterns					
	Crossed					Uncrossed
	1.5°	1.25°	1°	0.75°	0.5°	1°
Total number of comparisons (with and without occluder)	4	4	8	4	4	4
AV	4	4	7	4	4	4
BL	2	2	3	2	2	1
DS	0	0	2	0	-1	0

Table 1. A comparison of variances of slant difference estimates with and without the occluder placed at different disparity pedestals in Experiments 1 and 2. The numbers of comparisons that show significant variance between the unoccluded condition and the occluded condition are shown in the table ($p < .05$). Positive number indicates significantly greater variances when the occluder was absent than when it was present.

comparisons (i.e., for slant difference conditions) for each disparity pedestal that shows significant differences in variance from the non-occluder condition. Positive values indicate greater variance when the occluder was absent. Most of the comparisons except for one (DS at 0.5° crossed disparity) revealed that the variance of slant difference estimates was either not significantly different or was smaller when the occluder was present than when it was absent. Note that this trend is opposite to the prediction for slant difference estimates based on local disparity interactions (relative disparities) between the edges of the occluder and random-dot patches. In addition, the influence of the occluder was greatest when it was presented on a crossed disparity pedestal, and it was smallest when it was presented on an uncrossed disparity pedestal, suggesting the perceptual grouping influenced the decreased slant difference more than disparity or slant of the occluder.

The influence of slant contrast effects

Could the occluder have influenced perceived slant difference by producing slant contrast with the center random-dot patch? In two of our experiments, the slant of the occluder was the same as the surround but different from the slant of the center, so that any slant contrast induced by the occluder would influence the center more than the surround. In addition, the boundaries of the occluder were closer to the center patch than the surround patches. Thus, contrast between the slant of the occluder and center patch could have increased the perceived slant of the center patch more than the surround. When the center was slanted in the direction opposite to the surround, this would have increased the perceived slant difference, and when it was slanted in the same direction as the surround it would have reduced the slant difference. However, we find that the occluder reduced the slant difference for both directions of the center patch, and that the magnitude of slant difference between the occluder and center patch did not influence the amount that slant

difference between the central and surrounding patches was reduced. These results suggest that slant contrast produced by the occluder did not account for the decreased slant difference between the central and surrounding surfaces.

Perspective and disparity cue conflicts

In our experiments, sparse random-dot patterns without any clear boundary were used for the surrounding and the center surface patches to minimize the potential conflicts between stereoscopic cues and perspective cues for slant that can produce slant contrast (van Ee et al., 1999). Previous studies of slant contrast and slant assimilation usually used bars or shapes with clear boundaries and uniform surfaces (Fantoni et al., 2004; Gillam & Blackburn, 1998). In those experiments, there are conflicts between the perspective cue from the shape of the edges and the stereoscopic cues from binocular disparity. Our occluder also presented conflicts between perspective and disparity cues for slant because the occluder had a rectangular shape with clear boundaries and this could have reduced its apparent slant away from fronto-parallel (van Ee et al., 1999). The rectangle was intended to minimize disparity interactions between the horizontal edges of the occluder with the random-dot patterns and to avoid confusion of the occluder with the random-dot surfaces. It is unlikely that reduced slant estimates of the occluder caused by cue conflicts would affect slant assimilation because slant variations of the occluder in Experiment 3 had no influence on the magnitude of slant assimilation.

Amodal completion: a related phenomenon

The effect of the occluder on perceived slant difference that was found in the present set of experiments might be related to a perceptual grouping effect that has been referred to as amodal completion (Fantoni et al.,

2004). When one object partially occludes another, we perceive the separate visible portions of the occluded object as parts of a single object. The perceptual completion of the visible features is called amodal completion (Michotte, Thines, & Crabbe, 1991). “Amodal” refers to the fact that the occluded features cannot be seen and do not have any sensory input to the visual system such as luminance or color. Many studies of amodal completion have been carried out to investigate the phenomenon and its origin (Liu, Jacobs, & Basri, 1999; Nakayama, Shimojo, & Silverman, 1989; Shimojo & Nakayama, 1990; Yin et al., 2000). The weaker effect of the occluder when placed in uncrossed disparity is consistent with this hypothesis. However, we do not completely attribute our results to amodal completion, because the uncrossed disparity occluder also effected perceived slant, albeit reduced.

Does the occluder decrease slant contrast or increase slant assimilation?

The effects of the occluder on perceived slant differences could have resulted from either a reduction of slant contrast or an increase of slant assimilation. The goal was to compare perceived slant differences with and without the occluder and not to estimate the magnitude of the slant percept under each condition. The latter measure would quantify slant contrast and slant assimilation directly. Magnitude estimation was an effective way to indicate the change in perceived slant difference between conditions. However, the method cannot measure these directly because there is an unknown calibration between perceived slant and some independent measure (e.g., indicated slant difference) obtained from magnitude estimation. Thus, the reduction of perceived slant difference with the occluder could result from either a reduction of slant contrast, or an increase in slant assimilation.

We designed our random-dot stimuli to minimize slant contrast effects between the center and surround. The surfaces had rounded shapes and were composed of sparse irregularly spaced dots to minimize perspective and texture cues to slant to avoid cue conflicts with the disparity cues for slant and to minimize slant contrast effects without the occluder (van Ee et al., 1999). Thus, we believe that the occluder increased slant assimilation rather than reduced slant contrast although it could have had both effects.

The site of slant assimilation

The results from the present study suggest that the effects of an occluder on percepts of slant difference can be ascribed in part to stereo-slant assimilation, possibly resulting from perceptual grouping of surface patches.

The slant assimilation could occur at several sites in the visual system because slant perception involves binocular disparity, and the mapping of disparity to slant using distance and azimuth information (Backus et al., 1999). For example, it might occur at a level that processes the binocular disparities with enlarged receptive fields in the presence of an occluder that could average disparities in adjacent regions. Because our stimuli had similar azimuth and distance properties, slant assimilation probably did not involve changes in the mapping from disparity to slant. However, assimilation might also occur at a slant percept level. There could be feedback from top-down to a bottom-up process that could influence either size of disparity-selective receptive fields or the final slant percept when the surfaces are perceptually grouped.

Neurophysiological studies have shown that neurons are able to respond to stimuli that are perceptually grouped. Bakin, Nakayama, & Gillbert (2000) found that when a horizontal bar was put in front of two vertically aligned bars, some neurons in V2 that responded to one of the vertical bars increased their response rate compared to when there were only two vertical bars without the horizontal bar between them, and also when the horizontal bar was behind the vertical bars. Perceptual grouping is only realistic when the horizontal bar occluder is in front of the two vertical bars. Under this situation, the two vertical bars can be perceived as one long vertical bar that is occluded by a horizontal bar between them, and the receptive field for one vertical bar becomes larger to enclose the second bar that is perceptually connected to the first one. Another related finding comes from studies on perceived direction of ambiguous movement of gratings drifting in an aperture (i.e., the aperture problem). Duncan, Albright, & Stoner (2000) found that depth of the aperture edges affected the perceived motion direction of central gratings. They varied the relative disparity (stereo-depth) of different apertures edges independently of the disparity of the grating. When some regions of the aperture appeared closer and other regions farther away relative to the central grating pattern, the perceived motion direction was different than when the edges of the aperture had the same depth as the central grating. Usually, the perceived motion of the grating was determined by the aperture that was in front of it. They described a physiological correlate in which some neurons in MT responded to the perceived motion direction when background depth varied.

It appears that the visual system is able to encode perceptual grouping to influence the outcome of bottom-up processes for motion and depth. It is possible that the receptive fields for processing motion and disparity are enlarged when several surfaces are grouped together and that the slant percept of each surface patch is averaged among all the grouped surfaces, which leads to the slant assimilation.

Studies on binocular matching of the two retinal images (the correspondence problem) also suggest that

the relative disparity matching between small surface patches is influenced by whether the small surface patches appear to belong to one common surface or not (Schor & Zhang, 2005; Zhang, Berends, & Schor, 2003; Zhang, Cantor, Ghose, & Schor, 2004). These results suggested that perceptual grouping might influence the processing that selects relative disparities to optimize surface smoothness.

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