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Amodal completion impairs stereoacuity discrimination

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Abstract

Visual stimulus configuration can influence elementary visual processes. We provide empirical evidence to demonstrate this effect in stereoscopic depth discrimination. Two vertically aligned bars were presented in stereo such that one of them was closer to the human observer. Observers discriminated which of the two was closest. In the first, "occluded" condition, a horizontal bar, positioned closest in depth to the observer, was added to the display such that the two vertical bars perceptually completed to form a whole by connecting together behind the horizontal bar. In the second, control condition, the horizontal bar was placed furthest away from the observer such that there was a visible gap between the two vertical bars, which could no longer complete perceptually. We measured observers' psychometric functions using the method of constant stimuli, and found that their discrimination sensitivity d' was smaller when the two vertical bars perceptually completed than when they did not. We used a simple model to illustrate that when the two vertical bars perceptually completed, they also tended to be perceived as coplanar in the fronto-parallel plane. This consequence of completion made it more difficult to discriminate any difference in depth between the two vertical bars.

Keywords: Amodal completion; Stereodiscrimination; Perceptual completion; Bayes; Discrimination sensitivity; Bias

1. Introduction

The hypothesis that visual perception is an inference process (Helmholtz, 1924) places a great deal of emphasis on the role of prior knowledge about the visual world. In modern terms, Bayesian prior probability distribution presumably plays as important a role as stimulus information in determining the eventual percept that the visual system settles on (Kersten & Yuille, 2003; Knill & Kersten, 1991; Knill & Richards, 1996). However, despite its fruitful outcomes (Feldman, 2000; Mamassian & Landy, 2001; Weiss, Simoncelli, & Adelson, 2002), this approach remains controversial.

In a prominent article, Nakayama and Shimojo (1992) argued that, when stimulus information is ambiguous and consistent with several different configurations of the physical world, the final percept is completely determined by the likelihood of the physical layout, assuming a generic viewpoint. In other words, although the prior probability of viewpoint is assumed existent and uniformly distributed, the prior probability of the physical layout is not considered or, even if considered, plays no role.

In the current study, we will demonstrate that the prior probability distribution of physical layout is not only influenced by stereoscopic depth discrimination (and vice versa), but that it can also alter discrimination sensitivity. Before describing our study in detail, however, we will first review the background literature concerned with the influences of prior probabilities.

2. Background

2.1. Influence from amodal completion

From the perspective of signal detection theory, influences from priors may alter either discrimination bias,

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discrimination sensitivity, or both. From this perspective, alteration of bias is likely to occur at a later, decision stage; whereas alteration of sensitivity is likely to occur at an earlier, signal encoding stage. In this regard, alteration of sensitivity is stronger evidence of top–down influence. That is why, when only decision bias was found to have been altered, it was called "top-but-not-very-far-down" by Mussap and Levi (1995).

Mussap and Levi (1995) studied the possible top–down influence from amodal completion (i.e., perceptual completion behind occlusion) on 2D vernier acuity, i.e., the discrimination of two nearly collinear vertical bars with a small offset sideways (Westheimer, 1976; Wülfing, 1892). Subjects judged the direction of the offset (left, right, or zero). It was found that discrimination sensitivity d' was not influenced by amodal completion. Only the decision bias β was influenced when no feedback was provided, in which case subjects were more likely to say that the two vertical bars were collinear (i.e., zero offset).[2] This was therefore called by Mussap and Levi (1995) a "top-but-not-very-far-down" process. This result might be interpreted as follows. Although binocular disparity was used to manipulate the presence or absence of occlusion, the direction of the vernier offset was sideways in the fronto-parallel plane, not in depth. Furthermore, it has been shown that two parallel bars with an offset sideways do not strongly complete with each other (Kellman & Shipley, 1991). Given that depth difference is relatively more uncertain than difference in the fronto-parallel plane (Harris, McKee, & Watamaniuk, 1998), a stronger effect may be expected by manipulating occlusion for an offset that is in stereoscopic depth rather than in the fronto-parallel plane.

Stereoscopic discrimination in depth as a function of amodal completion was studied by Yin, Kellman, and Shipley (2000). A colored circular disk was presented in depth, either in front of or behind a gray rectangle. Behind this rectangle and disk, a third object, a colored oval shape completed itself amodally. Subjects discriminated whether the disk was in front of or behind the rectangle. It was found that discrimination sensitivity d' was reduced when the disk and the amodally completed oval shape shared the same color compared to when they had different colors or when the oval shape was absent. This indicates that when the oval and the disk shared the same color, the two shapes were grouped together to form a single surface in a single depth plane, therefore, making it more difficult to discriminate the disk's veridical depth relative to the rectangle's depth. There is, however, one aspect of the stimulus design in this study that could be improved. Since only the contour of the disk provided its stereoscopic depth information relative to the rectangle, when the disk was behind the rectangle, the disk "pulled" with it its surrounding region of the rectangle also away from the observer (there was no hole in the rectangle). This is analogous, assuming that the observer's viewing direction is top–down, to a circular Frisbee disk sitting on top of a rectangular mosquito net. This "behind" condition was in contrast to the condition when the circular disk was in front of the rectangle, with the latter's surface being perfectly planar. This stimulus difference might be why subjects were less accurate when the disk was behind than in front of the rectangle. This might be also why subjects were a little biased against choosing the disk as being behind.

Liu, Jacobs, and Basri (1999) also studied stereoscopic depth discrimination under amodal completion. They assumed that the stronger two planar surfaces were grouped together via amodal completion, the harder it would be to discriminate stereoscopic depth differences between these two surfaces. They found that amodal completion with convex contours made stereodepth discrimination more difficult than when concave contours were presented. Although, they conducted a pilot experiment to verify their assumption, the number of subjects were small (i.e., three). Clearly, additional experiments are needed to verify this assumption.

2.2. Contextual effects in stereodiscrimination

So far, we have reviewed the literature concerned with the influence of amodal completion on vernier and stereoacuity discrimination. More generally speaking, stereoacuity discrimination appears to be influenced by stimulus configuration, which is often referred to as contextual effects. In what follows, we will review contextual effects in stereoacuity discrimination. The overarching theme of the review is that contextual effects can be understood as cue interactions (Landy, Maloney, Johnston, & Young, 1995), of which amodal completion is an example cue that can be in conflict with stereodepth information.

Mitchison and Westheimer (1984) presented two parallel vertical bars in depth and asked subjects to discriminate which was closer. They found that discrimination threshold was greatly elevated when the two bars were connected by two horizontal bars to form a square. This is possibly because the monocular linear perspective cues of the square indicated a square in the fronto-parallel plane. In fact, even when the two bars were connected by a single horizontal bar to form a letter 'H', discrimination threshold was elevated (McKee, 1983). Perhaps for a similar reason, Mitchison and Westheimer (1984) also found an elevated depth discrimination threshold between two columns of dots when they were flanked by additional columns of dots to form a slanted plane. These additional columns provided additional binocular disparity information to potentially aid depth discrimination between the middle two columns. However, because all the dots formed into a square grid

[2] $d' = Z(\text{hit-rate}) - Z(\text{false-alarm-rate})$, $\beta = \text{normpdf}(Z(\text{hit-rate}))/\text{normpdf}(Z(\text{false-alarm-rate}))$, where normpdf is the normal probability density function. An intuitive way to understand the bias β is that it is the ratio of the y-coordinates of the two normal distributions when the x-coordinate is at the decision criterion. For example, when the criterion is set where the two normal distributions intersect, the decision is bias free $\beta = 1$.