STEREOSCOPIC MODULATION OF DA VINCI STEREOPSIS

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Abstract

The present study investigated how depth localization of unpaired monocular dots positioned close to a possible occluder (in so-called "da Vinci" stereopsis) was affected by an adjacent stereoscopic plane. We systematically manipulated the relative depth of the stereoscopic plane (defined by a sparse random-dot stereogram) to the occluder and to which eye the unpaired dots were presented. The results showed that the depth of the unpaired dots was strongly affected by that of the stereoscopic plane and the former could be predicted by extrapolating the latter when both the relative depth and the presented eye were ecologically valid. However, when either of the two factors was invalid, the influence of stereoscopic depth was much reduced and the perceived depth of the dots became ambiguous. These results suggest that da Vinci stereopsis can be strongly modulated by stereoscopic processing and the modulation is partially regulated by occlusive relations.

When a near object occludes a distant object, some or whole parts of the distant object become visible only to one eye. It has been demonstrated that this unpaired monocular part can be utilized in combination with the binocular area to recover a three-dimensional percept. The process has been named as "da Vinci" stereopsis (Nakayama & Shimojo, 1990). In da Vinci stereopsis, occlusive relations in the real world are taken into account so that both the eye of origin and the relative position to the occluding edge are critical for an appropriate interpretation of depth. That is, da Vinci stereopsis works appropriately if the right eye sees a monocular point on the right side of the occluder and the left eye sees one on the left side.

In previous studies of da Vinci stereopsis, an unpaired stimulus was relatively isolated from other objects in the stimulus display (e.g., Nakayama & Shimojo, 1990; Häkkinen & Nyman, 1996). However, in the everyday situation, a near object often only partially occludes a distant object, so that a part of the distant object is located as a binocular region nearby the unpaired region. In this case, as the unpaired region is just an extension of the half-image of the binocular region, a strong binocular-monocular interaction between classical Wheatstone and da Vinci stereopsis would be expected and even depth extrapolation from the binocular region might be observed. To explore this possibility, the present study investigated the depth localization of unpaired dots flanked with a sparse random-dot stereogram slanted vertically. In the present display, monocular and binocular regions were composed of random dots of similar attributes and thus, under suitable conditions, the stimulus represents a partially occluded object. The effects of ecological validity of the stimulus display on possible binocular-monocular interaction were also investigated by systematically manipulating the presented eye (to which eye the unpaired dots were presented) and the relative depth of the stereoscopic plane defined by a random-dot stereogram to a binocular textured plane (a possible occluder).

Method

The stimuli were presented on a 21” Sony Trinitron display (GDM-F520, 1280×1024 pixels, 120 Hz). Stereoscopic effects were created by dividing the screen into two areas which were seen by the left and right eye separately through a mirror-stereoscope. The viewing distance was 88 cm and the background luminance was 30.5 cd/m^2.

The stimulus consists of three objects: a textured occluding plane, a plane created by a sparse random-dot stereogram (RDS), and unpaired dots flanked with the RDS (Fig. 1). The occluding plane was 91.6×271.3 min arc and its mean luminance was 5.2 cd/m^2. The sparse RDS was always located to the right of the occluder and composed of 98 dots. The slant of the RDS plane around the vertical axis was 14° forward, frontparallel (0°), or 14° backward. The forward condition refers to the one where the left edge of the RDS plane was slanted forward (toward the observer), while the backward condition to the one where it was slanted backward (away from the observer). The slant of the RDS plane was produced by adjusting binocular disparity of random dots in the half-images. The sizes of the RDS half-image were 188.8×271.3 and 150.8×271.3 min arc in the forward and backward conditions and the former size was used in the frontparallel condition. The horizontal size of the dots was also adjusted (9.1×7.8 vs. 7.8×7.8 min arc) so that the dots themselves appeared slanted (Ogle, 1962). The unpaired stimulus was composed of 7 vertically aligned dots of 8.9×7.8 min arc and presented to the right (19 min arc) of the occluder and to the left (2.2 min arc) of the RDS image. Presenting the unpaired dots to the right eye satisfied the occlusive relation in the natural environment and thus it was called the valid eye condition. In the invalid eye condition, the unpaired dots were presented to the left eye which could not see the occluded area in the natural environment. The RDS plane was nearer or farther than the occluder. The disparity of the left edge of the RDS plane to the occluder was fixed to +23.5 or -23.5 regardless of the slant of the RDS plane in the nearer or farther condition, respectively. This disparity was defined by horizontally shifting the RDS half-image where the unpaired dots were not flanked. The luminance of dots was 0 cd/m^2.

(A)

(B)

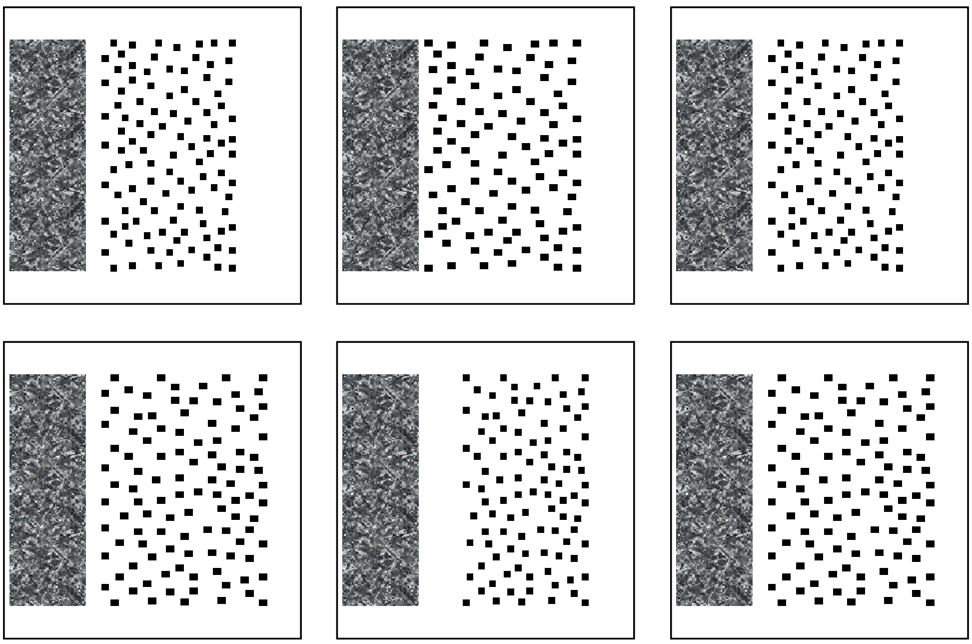

Fig. 1. Examples of experimental stimuli. Cross-fusers should fuse the left and center images and uncrossed fusers should fuse the center and right images. (A) Valid eye, farther, and slanted backward condition. (B) Valid eye, nearer, and slanted forward condition.

Perceived depth of the unpaired dots was measured using the method of constant stimuli. In each trial, the observer was first asked to judge apparent depth of the unpaired dots, and then depth probes (8.9×8.9 min arc, positioned 24.6 min arc above and below the occluder) were presented in one of 5-6 different locations in depth. The observer judged the relative depth of the probe to the unpaired dots. The measurement was repeated 20 times for each probe position under all stimulus conditions. The point of subjective equality in apparent depth was determined based on the psychometric function.

Four observers participated in this study. Three of them were naïve about the purpose of the experiment.

Results and Discussion

The results were shown in Fig. 2. The valid eye and farther condition (top-left panel of Fig. 2) refers to the condition in which the RDS half-image flanked with the unpaired dots was presented to the right eye and the RDS plane was located behind the occluder (see Fig. 1 (A) for an example of the stimulus). In this condition, the stimulus effectively represented an object which was partially occluded by the near plane and thus both the relative depth and the presented eye were ecologically valid. The results showed that apparent depth of the unpaired dots was strongly affected by stereoscopic depth. The unpaired dots were perceived close to the location linearly extrapolated from the RDS plane (thick line) and the perceived depth was generally varied with the slant of the plane. However, when either of the two factors was invalid, that is, when the RDS place was located in front of the occluder (valid eye and nearer condition, top-right panel of Fig. 2) or when the unpaired dots were presented to the invalid eye (invalid eye and farther condition, bottom-left panel of Fig. 2), the influence of stereoscopic depth was reduced and the perceived depth of the dots became ambiguous and unstable. But still, the effect of stereoscopic depth can be seen in that the unpaired dots were attracted toward the RDS plane, although under these conditions some observers reported difficulty of depth judgment and the slope of the psychometric functions became shallower. When both factors were invalid (invalid eye and nearer condition, bottom-right panel of Fig. 2), the effect of the stereoscopic depth nearly vanished and the unpaired dots were located at about equidistance to the occluder (around zero min arc on the ordinate). It should be noted that the RDS plane could be interpreted as an occluder in some cases under the invalid eye condition and depth of the unpaired dots could be determined by their occlusive relation to the RDS plane alone. However, if this occlusive relation strongly affected the depth localization of the unpaired dots, the dots would have been located behind the RDS plane. This was not generally the case in the invalid eye and farther condition, although the results in the invalid eye and nearer condition might be partially affected by this effect.

The present results showed that depth localization of an unpaired object could be strongly modulated by stereoscopic processing when the unpaired object was in the horizontal vicinity of an additional binocular plane. Häkkinen & Nyman (1996) found similar effects but they were asymmetric in depth: only an uncrossed object biased depth localization of the unpaired dot to uncrossed direction. Stronger and less asymmetric modulation found in the present study probably resulted from consistency in stimulus attributes between the unpaired and binocular objects. Whereas Häkkinen & Nyman (1996) used a distinct rectangular plane as the additional object and located it above the occluder, the present study used a sparse RDS and located it next to the unpaired dots so that the dots could be interpreted as an extension of the binocular object. Stereoscopic modulation of the depth localization process in da Vinci stereopsis could be accounted for by depth spreading from an adjacent stereoscopically unambiguous area. The strength of the depth spreading would be regulated by occlusive relations but, at least in some situations, could not be prevented completely.

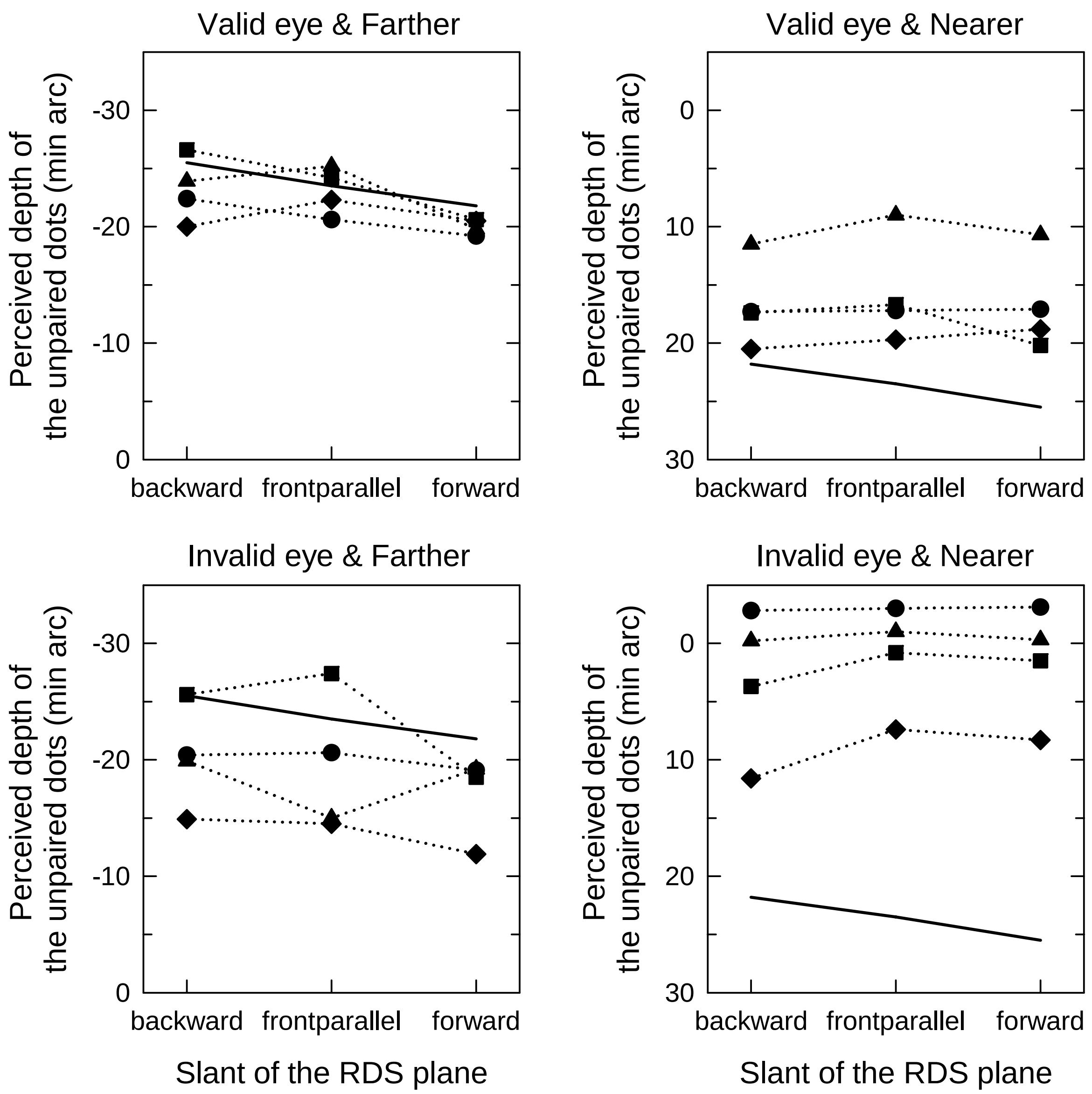

Fig. 2. Perceived depth of the monocular unpaired dots as a function of the slant of the adjacent RDS plane. Each symbol shows the result for different observers. The thick line shows the prediction based on extrapolation of the stereoscopic slant.

Acknowledgements

This research was supported by JSPS grant (#19530650).

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