Temporal Factors of Human Depth Perception

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Abstract

I introduce two experiments that investigate temporal factors of stereopsis: one is for depth perception and the other is for perception of motion in depth. Both studies show that there are multiple mechanisms to process depth information with different temporal characteristics.

1. Introduction

We see the world in motion in general, and the retinal images keep changing according to the motion of objects and the observer. It is not surprising that temporal property is one of the important factors in visual processing. Indeed, the visual system has great influence of stimulus temporal characteristics in the retinal images. Depth perception should also be influenced by temporal characteristics since the detection of the features in each retinal image precedes the depth analysis[1]. In this paper, I describe two experiments that investigate temporal factors of stereopsis: one is for depth perception and the other is for perception of motion in depth. Both experiments show that temporal characteristics for depth perception are not independent of spatial factors such as stimulus spatial frequency, disparity or binocular correlation.

2. Depth Perception

To investigate the spatiotemporal frequency tunings for stereopsis, we measured contrast sensitivity for depth identification with variable spatiotemporal frequencies and disparities using drifting sinusoidal gratings[2]. The observer judged the relative depth between a set of grating stimuli (which of the two appeared to be closer) with different luminance constant of stimulus gratings and contrast threshold was determined by the method of constant stimuli for each combination of spatial frequency, temporal frequency and disparity. Although our measurements were contrast threshold, the data include the information of stereo acuity (disparity threshold) since threshold was measured with variety of disparities.

Results show that all of spatial frequency, temporal frequency and disparity influence sensitivity to depth perception. The effect of disparity is different among different spatial frequencies. With a high spatial frequency, the sensitivity peaks at a small disparity while it peaks at large disparity with a low spatial frequency (size-disparity correlation). One of a simplest explanation of the effect is that the disparity in terms of phase determines the sensitivity. This is true, at least partially. If the results are plotted as a function of phase disparity sensitivity peaks at about 50-degree phase disparity in all spatial frequencies. The effect of phase disparity is similar also in all temporal frequency conditions.

However, phase disparity is not only factor to determine the sensitivity of stereopsis. The value of the peak sensitivity differs among different spatial and temporal frequency conditions. The dependency of sensitivity on phase disparity can be predicted from a disparity energy model with a single channel. The disparity energy model is a model of a disparity-sensitive complex cell proposed by Ohzawa and his co-workers[3]. A simulation with a disparity energy model reveals that the shift of the peak spatial frequency with the stimulus disparity and the shift of the peak disparity with the stimulus spatial frequency, showing size-disparity correlation. Although size-disparity correlation of stereopsis is often considered as the evidence of multiple stereo channels, the simulation shows that this is not a sufficient condition. The model does not consider any temporal factor, but a signal channel should have a single spatiotemporal characteristic. Therefore, the effect of temporal frequencies on the sensitivity and spatial frequency tuning function supports strongly that multiple channels contribute to the disparity detection.

3. Motion in Depth

In addition to the luminance modulation, spatiotemporal modulation of depth also influences depth perception[4]. There is an appropriate distance between the two stimuli for detecting depth difference between them. Spatiotemporal frequency tunings can be considered for depth modulation, if we consider random-dot stereograms of sinusoidally corrugated surfaces changing in depth, whose modulation changes in time. When motion in depth is considered, there are two binocular cues to detect motion direction in the 3D world[5, 6]. One is that based on disparity change in time (DCT) and the other is that based on inter-ocular velocity differences (IOVD). In the former case, disparity is detected first, and then its change over time is calculated. In the latter case, monocular velocities are calculated first, and then compared. Since motion in depth can be seen in dynamic random-dot stereograms, where no coherent monocular motion exists, disparity change in time is used to see motion in depth. In addition, evidence to show the existence of the different mechanisms to detect the different cues is being accumulated in variable types of experiments.

We investigated the effect of temporal frequency on motion in depth based on DCT and IOVD. The difference in the analysis in the visual system could cause the difference in temporal characteristics and the two mechanisms may have different roles in seeing motion in depth. To isolate velocity cues, we removed the binocular correlation from the original random-dot stereogram, replacing one of random-dot patterns by a new one. Since the motion of monocular stimuli was the same as that in the original, the stimulus contained IOVD cues. In this condition, there was no disparity cue to form any surface or structure while monocular motion cues remained. To isolate disparity cues, we replaced the patterns from time to time with keeping binocular correlations. Since the motion of monocular stimuli was the same as than in the original, the stimulus contained DCT cues. We measured contrast sensitivity as a function of temporal frequency for motion in depth in conditions with different types of motion in depth.

The results show that the temporal frequency tuning differs between the IOVD and DCT conditions. The one in the IOVD condition is bandpass and that in the DCT condition is lowpass. They suggest that the underlying mechanism sensitive to IOVD plays a more important role to see fast motion whereas the one sensitive to DCT plays a more important role to see slow motion.

4. Summary

We showed that temporal factors, not only the temporal frequency tuning itself but also the relationship with spatial factors (spatial frequency or binocular correlation), are crucial for depth perception. The knowledge of the temporal factors of stereopsis should be useful to design and evaluate 3D displays and the 3D contents.

5. References

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