Does peri-saccadic spatial compression affect computation of motion correspondence?

Masahiko TERAO*, *2, *3, Ikuya MURAKAMI*, and Shin'ya NISHIDA*3

The University of Tokyo*, JSPS Research Fellow*1, NTT Communication Science Laboratory*3

When multiple elements are present in an apparent-motion display, the visual system must solve a motion correspondence problem. The proximity between matching elements is a factor determining motion correspondence. Previous studies have suggested that the proximity computation uses distances in retinal coordinates (e.g., Ullman, 1979), but we recently demonstrated that distances in environmental coordinates are also considered during smooth pursuit eye movement (Terao et al., 2008, SfN). Our finding indicates the processing stage is later than the integration of retinal inputs with extra-retinal signals of smooth pursuit eye movements. Here we report that the subjective proximity modulated by extra-retinal signals of saccade determines the motion correspondence computation, but consistent with the hypothesis that peri-saccadic space compression affects motion correspondence, this effect weakens as the saccadic amplitude decreases. Our findings suggest that the proximity computation for motion correspondence is based on the apparent distance, which is affected the extra-retinal signals of saccade.

Key words: peri-saccadic space compression, motion correspondence

Introduction

When multiple elements are present in an apparent motion display, the visual system must solve a motion correspondence problem. An important factor in determining motion correspondence is the proximity between matching elements. Previous studies have suggested that the proximity computation uses distances in retinal coordinates (e.g., Ullman, 1979). However, we recently demonstrated that the proximity computation also considers distances in partially compensated environmental coordinates during smooth pursuit eye movement (Terao, Kato, Murakami, Yagi, & Nishida, 2008, SfN). Our finding suggests that the processing stage of motion correspondence occurs after retinal inputs are integrated with extra-retinal signals of smooth pursuit eye movement.

Extra-retinal signals of saccade also dissociate retinal coordinates and subjective coordinates (e.g., Ross, Morrone, & Burr, 1997). Herein we examine whether extra-retinal signals of saccade affect the motion correspondence computation. We tested whether peri-saccadic space compression affects the perceptual solution in a motion-quartet stimulus. Depending on the H/V ratio, which indicates the relationship between the horizontal and vertical distance of the jump size, the motion quartet yields a bi-stable apparent motion in either the horizontal or vertical direction. For example, when the horizontal distance is shorter than the vertical distance, the H/V ratio is less than 1, and the perceived direction of motion is more likely to be horizontal. When the horizontal and vertical distances are the same, the H/V ratio is 1, and the perceived motion direction is ambiguous.

Peri-saccadic space compression is the mislocalization of briefly flashed stimuli just before a saccadic onset toward the position of a saccadic target (Ross et al., 1997). Because a large compression occurs only toward the saccade endpoint, horizontal proximity becomes subjectively closer than vertical proximity when two stimulus frames are presented before a horizontal saccade. If subjective proximity determines correspondence during a horizontal saccade, then the probability of perceiving horizontal motion increases even though the actual inter-disk distance remains constant.

Methods

Observers in this study included one of the authors (T.M.) and three volunteers who were unaware of the purpose of the experiments. Visual stimuli were presented on a CRT monitor (120-Hz refresh rate) (Mitsubishi, RDF223H) driven by a computer (Apple Mac Pro Quad-core, 2×2.8 GHz) through a graphic card (NVIDIA Quadro FX 5600).

Two diagonally opposing pairs of disks (inter-disk distance of 6 deg) centered at the saccade target were flashed (just one frame) successively with the 50 ms SOA (Fig. 1). We manipulated the H/V ratio by varying the horizontal distance between 3–9 deg, while keeping the vertical distance fixed at 6 deg.

Two conditions were tested: a saccadic condition and a fixation condition. In the saccadic condition, observers were asked to make a saccade to the remembered target position.

* Graduate School of Arts and Sciences, University of Tokyo, 3–8–1 Komaba, Meguro-ku, Tokyo 153–8902 Japan. E-mail: masahiko_terao@mac.com

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immediately after the fixation point disappeared (memory-guided saccade). In the fixation condition, observers were asked to maintain fixation after the fixation point disappeared. If the second stimulus onset exceeded — 50 to 0 ms before the onset of saccade, the trial was excluded. Consequently, the retinal images of the motion quartets were the same for these two conditions. Additionally, subjects were asked to report the perceived direction of the apparent motion. We recorded eye movements using a video-based eye tracker with a sampling rate of 250 Hz.

Results and Discussion

Figure 2 shows the results of the large (8 deg) and small (4 deg) saccade amplitudes for one participant. For the balanced H/V ratio, the perceived direction, which is ambiguous under the fixation condition, was almost always horizontal in the large saccade conditions. Additionally, the psychometric function for the saccadic condition shifted to a larger H/V ratio. In contrast, when the saccade amplitude was small, the effect weakened. Similar results were obtained for the other three observers. These findings indicate that saccade affects motion correspondence.

Additionally, our results are consistent with a peri-saccadic change of subjective proximity. The compression effect decreases as the saccade amplitude decreases (e.g. Lavergne et al., 2010). In our preliminary experiment, we measured how much peri-saccadic space compression occurred in the current display; the amount of peri-saccadic space compression is similar to the results in previous studies. Hence, to determine whether subjective proximity can account for the perceived direction of motion, we re-plotted the current data against the subjective H/V ratio instead of the physical H/V ratio. If subjective proximity determines correspondence, then the psychometric functions in the fixation and saccadic conditions should be identical when the subjective H/V ratio is used as the horizontal axis. This was indeed what we found.

The current findings suggest that the proximity computation for motion correspondence is based on the space affected by the extra-retinal signals of saccade and that motion correspondence processing occurs after integration between the extra-retinal signals of saccade and retinal displacement. Additionally, our results indicate that the peri-saccadic position error is not merely a perceptual change of a position, but also affects later processing utilizing positional information.

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References