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Capture of visual direction in dynamic vergence is reduced with flashed monocular lines ☆

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Abstract

The visual direction of a continuously presented monocular object is captured by the visual direction of a closely adjacent binocular object, which questions the reliability of nonius lines for measuring vergence. This was shown by Erkelens, C. J., and van Ee, R. (1997a,b) [Capture of the visual direction: An unexpected phenomenon in binocular vision. Vision Research, 37, 1193–1196; Capture of the visual direction of monocular objects by adjacent binocular objects. Vision Research, 37, 1735–1745] stimulating dynamic vergence by a counter phase oscillation of two square random-dot patterns (one to each eye) that contained a smaller central dot-free gap (of variable width) with a vertical monocular line oscillating in phase with the random-dot pattern of the respective eye; subjects adjusted the motion-amplitude of the line until it was perceived as (nearly) stationary. With a continuously presented monocular line, we replicated capture of visual direction provided the dot-free gap was narrow: the adjusted motion-amplitude of the line was similar as the motion-amplitude of the random-dot pattern, although large vergence errors occurred. However, when we flashed the line for 67 ms at the moments of maximal and minimal disparity of the vergence stimulus, we found that the adjusted motion-amplitude of the line was smaller; thus, the capture effect appeared to be reduced with flashed nonius lines. Accordingly, we found that the objectively measured vergence gain was significantly correlated ($r = 0.8$) with the motion-amplitude of the flashed monocular line when the separation between the line and the fusion contour was at least 32 min arc. In conclusion, if one wishes to estimate the dynamic vergence response with psychophysical methods, effects of capture of visual direction can be reduced by using flashed nonius lines.

Keywords: Binocular visual direction; Vergence; Eye movements; Nonius lines

1. Introduction

In monocular vision, the perceived direction of an object is specified by the geometry describing the position of the object and the eye: each retinal location is associated with a certain visual direction. These rules for monocular vision were traditionally expected to be also valid for monocular objects that are presented combined with binocular objects, since Wells-Hering's laws of visual direction state that the visual directions of the right and left eye are transferred unaltered to the cyclopean eye (Howard & Rogers, 2002). According to these rules, the vergence angle between the visual axes of the two eyes can be measured psychophysically (i.e., subjectively) from the perceived misalignment of two physically aligned monocular objects that are presented separately to the two eyes; typically two dichoptic nonius lines are used (Shimono, Ono, Saida, & Mapp, 1998).

However, research has shown that the rules of visual direction are violated in particular conditions, as summarized by Howard and Rogers (2002). One of these conditions refers to dynamic vergence eye movements. Erkelens and van Ee (1997a, 1997b) presented a random-dot fusion target that moved sinusoidally in counter phase in each eye by ±40 min arc at a frequency of 0.75 Hz (Fig. 1); this dynamic target appeared stationary during vergence eye

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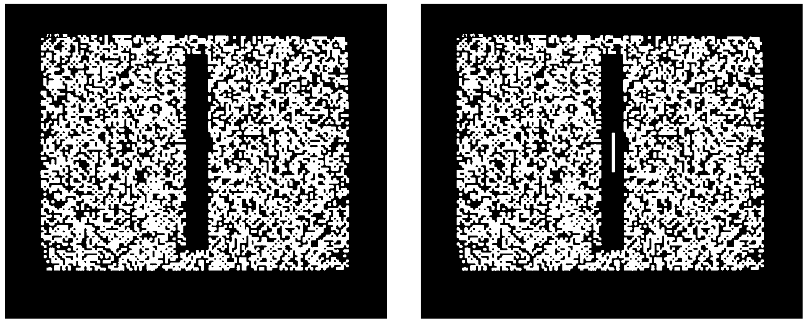

Fig. 1. Random-dot patterns that were presented to the right and left eye, respectively, and moved in counter phase to induce periodical vergence eye movements. The patterns contained a centre dot-free gap of constant height (20 deg), the gap width was 16, 44, 80, or 144 min arc in different experimental conditions. A vertical line (4 deg high and 16 min arc wide) was centered in the gap of either the right or the left eye. This line moved horizontally with the same frequency and phase as the corresponding random-dot pattern; the motion-amplitude of the line was adjusted until the line appeared as (nearly) stationary. In Experiment 1, the size of the random-dot patterns was 40 × 40 deg and in Experiment 2 it was 30 × 24 deg (horizontal × vertical); the latter is shown in this figure.

movements. In a centre dot-free gap of the random-dot target, they presented a continuously visible monocular line that moved in phase with the fusion stimulus in one eye, while subjects adjusted the motion-amplitude so that the line appeared stationary. When the gap was narrow, this adjusted motion-amplitude of the line was the same as that of the fusion target (±40 min arc). This would mean perfect vergence eye movements, provided the line were a valid vergence indicator. Since large vergence errors were observed in this condition, the stationary perception of both the random-dot pattern and the monocular line (when both move with a ±40 min arc amplitude) means that a continuously presented monocular line (adjacent to a fusion contour) received the visual direction of the fusion stimulus, or—in other words—the line is represented as part of the binocular random-dot pattern, irrespective of the actual vergence errors. This effect of capture of visual direction gradually declined with increasing separation between monocular line and fusion contour.

Thus, Erkelens and van Ee (1997a, 1997b) and further research reviewed by Howard and Rogers (2002) have identified conditions where the laws of visual directions are invalid, i.e., monocular lines do not measure the vergence angle in dynamic vergence or do not indicate the visual direction in stereograms. However, other studies suggest that capture of visual direction seems not to play a role in all conditions where monocular lines are used for measuring vergence. A stationary fusion stimulus in a single depth plane is an important condition in clinical testing the vergence system, e.g., for measuring fixation disparity (Evans, 2002; Mallett, 1974). Two studies varied the separation between a stationary fusion stimulus and the nonius lines to investigate possible modification of the subjectively measured fixation disparity (as predicted by capture of visual direction). However, Ukwade (2000)—using flashed nonius lines—did not find a change in fixation disparity up to a separation of 0.6 deg. Similar, Jaschinski, Kloke, Jainta, and Buchholz (2005) did not find a change up to a separation of about 3.3 deg (neither with flashed nor with continuous nonius lines); at larger separations, changes in fixation disparity occurred with flashed nonius lines in some subjects, but the nature of this effect differed from capture of visual direction.

Further, Popple, Findlay, and Gilchrist (1998) flashed nonius lines for 160 ms following a 230 ms vergence step stimulus by changing the absolute disparity of a fusion stimulus: they found good agreement between nonius results and objective vergence eye movement recordings and concluded that "alignment of nonius flashed subsequently to a stimulus provides a reliable measure of vergence." Dichoptic nonius lines flashed after a step stimulus were used in several studies and provided physiologically plausible results (e.g., Fredenburg & Harwerth, 2001; Jaschinski, 2004; Mallot, Roll, & Arndt, 1996; Popple, Smallman, & Findlay, 1998b).

Thus, on the one hand some studies found valid estimations of vergence with flashed nonius lines (even in conditions of vergence dynamics) while—on the other hand—studies reporting on capture of visual direction used monocular lines that were continuously visible. Therefore, we investigated in the present study whether the capture effect might be absent or reduced if a monocular line is presented in a series of short flashes. We expected that the process of transferring the visual direction from the fusion stimulus to the monocular line might require a certain amount of time; thus, capture might not occur, if the monocular line is presented for a shorter period only. A possibility to separate the fusion stimulus and the monocular line temporally was mentioned by Shimono et al. (1998).

Thus, we applied the dynamic vergence paradigm of Erkelens and van Ee (1997a, 1997b) to test whether capture of visual direction might be reduced with a flashed monocular line (Experiment 1) which may allow for subjective vergence measures that are correlated with the objectively measured vergence response (Experiment 2).

2. Methods

2.1. Subjects

In Experiment 1, the six subjects were experienced in visual experiments and familiar with the aims of the study; they used trial lenses to correct for ametropia (and presbyopia in one case). In Experiment 2, we had