Testing Computational Theories of Motion Discontinuities: A Psychophysical Study *

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Abstract. This study reports results from three patients with bilateral brain lesions (A.F., C.D., and O.S.) and normal observers on psychophysical tasks, which examined the contribution of motion mechanisms to the extraction of image discontinuities. The data do not support the suggestion that the visual system extracts motion discontinuities by comparing fully encoded velocity signals ([NL]; [Clo]). Moreover, the data do not support the suggestion that the computations underlying discontinuity localization must occur simultaneously with the spatial integration of motion signals ([Kea]). We propose a computational scheme that can account for the data.

1 Introduction

In this paper, we test theoretical proposals on the organization of motion processing underlying discontinuity extraction. We investigate performance on three psychophysical motion tasks of three patients with focal brain lesions involving the neural circuits mediating specific aspects of motion perception and address the possible implication of these results for the validity of theories of motion discontinuity.

2 Subjects and Methods

Normal naive observers with good acuity and contrast sensitivity, and no known neurological or psychiatric disorders, and three patients (A.F., C.D., and O.S.) with focal bilateral brain damage resulting from a single stroke participated in an extensive psychophysical study of motion perception. MRI studies revealed that the patients' lesions directly involved or disconnected anatomical areas believed to mediate visual analysis. The rationale for including these three patients in the study was their good performance on static psychophysical tasks, their normal contrast sensitivity, and good performance on some motion tasks but their selective poor performance on several other visual motion tasks. All the patients and healthy volunteers signed the Informed Consent form according to the Boston University human subjects committee regulations. Detail of the psychophysical experiments and of the experimental setting can be found in [Vea1], [Vea2], and [Vea3].

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3 Results

3.1 Experiment 1: Localization of Discontinuities

We addressed the problem in which the subjects had to localize the position of discontinuities defined by relative direction of motion. The stimuli (similar to those used by Hildreth– [Hil]) were dense dynamic random–dot patterns. The display was constructed in such a way that there was a discontinuity in the velocity field along a vertical line (Figure 1a). Along the side was a 1.4 deg^2 notch whose distance from the point of fixation varied along the vertical axis from trial to trial, but which remained within 2 deg of visual angle from the black fixation mark. The vertical boundary and the notch were entirely defined by the difference in direction of motion between the left and right of the boundary, and were not visible in any static frame. Each displacement was performed in one screen refresh and was synchronized with the screen to reduce flicker (see *Notes and Comments*).

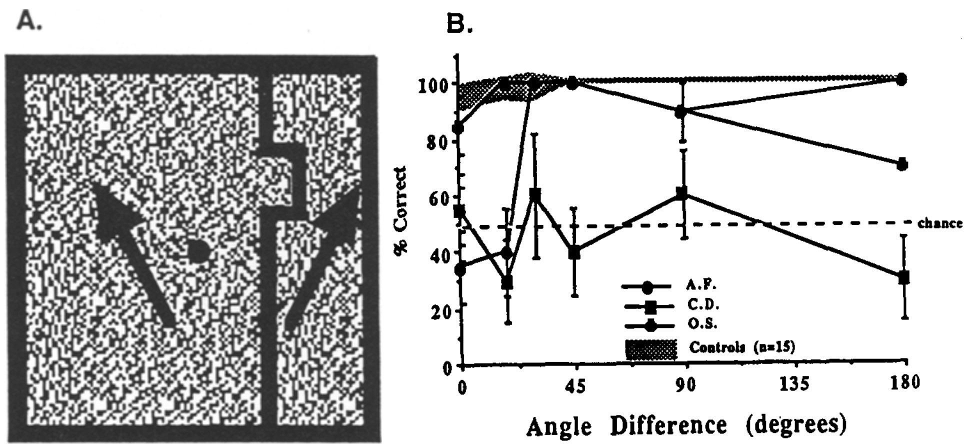

Fig. 1. Localization of discontinuities

Figure 1b shows that the normal subjects and O.S. performed the task essentially without error for all conditions. In contrast, patient C.D. was severely impaired at all conditions. Because the patients A.F. and C.D performed at chance in the pure temporal–frequency condition (0°), we conclude that they could not use this cue well enough to localize discontinuities.

3.2 Experiment 2: Local–Speed Discrimination

In this experiment, the stimuli consisted of two sparse dynamic random dot cinematograms displayed in two rectangular apertures (Figure 2a). In any single trial, each dot took a two–dimensional random–walk of constant step size, which was defined by the speed. The direction in which any dot moved was independent of its previous direction and also of the displacements of the other dots. The speeds of the dots was uniform and was assigned independently to each aperture. A base speed of 4.95 deg/sec was always compared to five other speeds, giving speed ratios of 1.1, 1.47, 2.2, 3.6, and 5.5. The assignment of the highest speed to the top or bottom aperture was pseudo randomly selected.

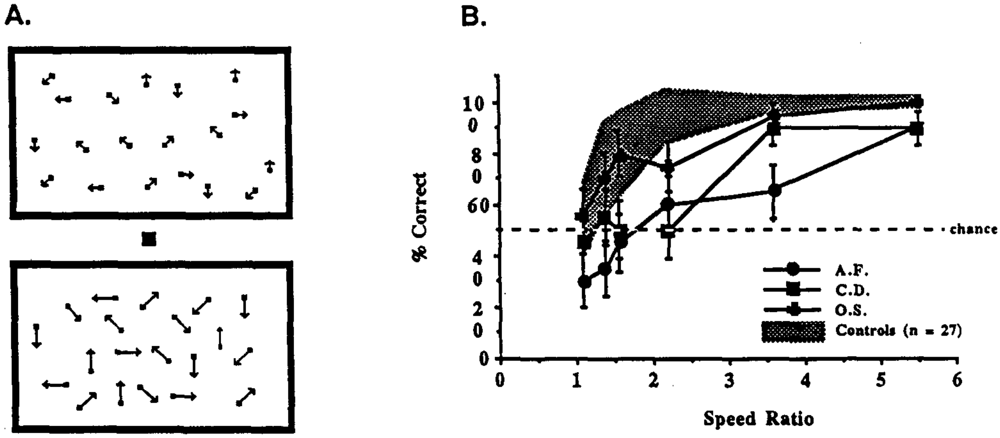

Fig. 2. Local speed discrimination

Subjects were asked to determine which of the two apertures contained the faster moving dots. Figure 2b shows that in comparison to the control group and O.S., who were performing almost perfectly for the 1.47 speed ratio, A.F. had a very severe deficit on this speed discrimination task. Similarly C.D was also impaired on this task, but to a lesser degree than A.F.

3.3 Experiment 3: Motion Coherence

In the third experiment, the stimuli were dynamic random–dot cinematograms with a correlated motion signal of variable strength embedded in motion noise. The strength of the motion signal, that is the percentage of the dots moving in the same, predetermined direction, varied from 0% to 100% (Figure 3a). The algorithm by which the dots were generated was similar to that of Newsome and Paré's ([NP]), which is described in detail in [Veal], [Vea2], and [Vea3]. The aim of this task was to determine the threshold of motion correlation for which a subject could reliably discriminate the direction of motion.

Figure 3b shows that the mean of the motion coherence threshold of the normal subjects (n=16) was 6.5% for left fixation and 6.9% for right fixation. The patient A.F. was significantly impaired this task. His direction discrimination threshold was 28.4% for left fixation and 35.2% for right fixation. Similarly, O.S. was very impaired on this task. In contrast, C.D.'s performance was normal when the stimulus was presented in the intact visual field, but she could not do the task when the stimulus was presented in the blind visual field.

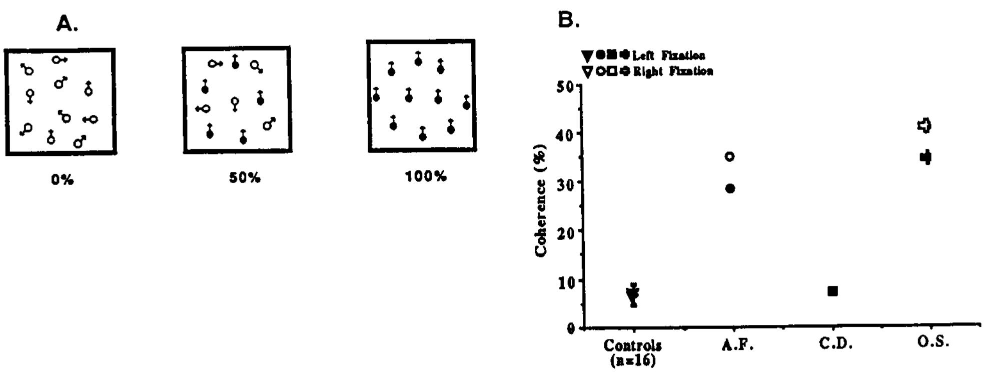

Fig. 3. Motion coherence

4 Discussion

4.1 Computation of Visual Motion

It has been theorized that comparisons between fully encoded velocity signals underlie localization of discontinuities ([NL]; [Clo]). However, our data do not support this suggestion, since A.F., who could not discriminate speed well, had a good performance in the localization–of–discontinuities task.

Our data also address the issue of whether the computations underlying discontinuity localization and motion coherence occur simultaneously in the brain. These possibilities are suggested by theories based on Markov random fields and line processors ([Kea]). Such theories would predict that if the computation of coherence is impaired, then so is the computation of discontinuity. Our data do not support this simultaneous–damage prediction as C.D. performed well on the coherence task, but failed in the localization–of–discontinuities task. Further evidence against a simultaneous computation of discontinuities and coherence comes from A.F. and O.S., who were good in the localization–of–discontinuities task but very impaired in the coherence task.

From a computational perspective, it seems desirable to account for the data by postulating that the computation of motion coherence receives inputs from two parallel pathways (Figure 4). One pathway would bring data from basic motion measurements (directional, temporal, and speed signals). The other pathway would bring information about discontinuity localization (see [Hil] and [GY] for theoretical models) to provide boundary conditions for the spatial integration in the computation of motion coherence ([YG1]; [YG2]). According to this hypothesis, it is possible that different lesions may cause independent impairments of discontinuity localization and motion coherence.

Notes and Comments. In Experiment 1, flicker was not completely eliminated, since at 0 angular difference the notch was still visible, as if it was a twinkling border. A possible explanation for this apparent flicker is that the dots inside the notch had shorter lifetimes and thus were turned on and off at a higher temporal frequency.

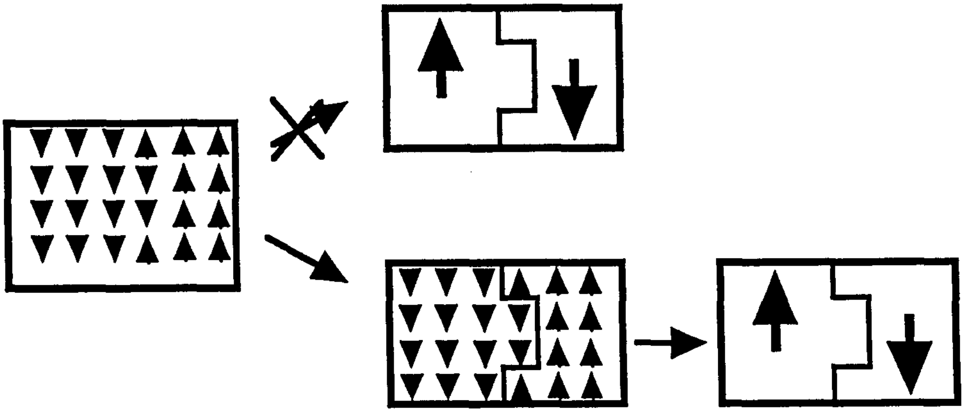

Fig. 4. Two models of motion coherence and discontinuities

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