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Motion grouping impairs speed discrimination

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Abstract

Discriminating between two speed signals is harder when they are seen as part of a single trajectory, compared to the case when they appear as distinct entities. Observers were asked to judge which half of a display had dots that were moving faster. This was done under two main conditions: when dot motion appeared to continue across the boundary between the two halves, and when it moved parallel to the boundary. Speed discrimination thresholds were elevated when motion in the two halves appeared to cross the boundary compared to the case when motion was parallel to the boundary. Extensive practice improved performance until speed discrimination in the two cases was virtually indistinguishable. The addition of noise caused the original effect to reappear, i.e., thresholds were elevated when motion continued across the border. Our results suggest that the local differences in velocity on either side of border are ignored when motion appears to cross the border. Instead the visual system seems to enforce an a priori assumption that when motion continues across a boundary it belongs to a common motion path.

Keywords: Motion trajectory; Speed discrimination; Prior visual experience; Segmentation; Acceleration

1. Introduction

Numerous studies have shown that human observers are not very sensitive to visual acceleration. In fact, Weber fractions for detecting a change in the ongoing velocity of a moving target are typically between 0.15 and 0.3, values that are several times higher than speed discrimination for spatially or temporally segregated stimuli (Bravo & Watamaniuk, 1995; Gottsdanker, 1956; Snowden & Braddick, 1991; Watamaniuk & Duchon, 1992). To explain the human inability to detect acceleration, Nakayama (1985) suggested that velocity signals were integrated for a substantial duration after their initial encoding. This second-stage integrator would smooth the velocity field and reduce noise. Alternatively, velocity signals that are seen as part of the same surface or as following a common trajectory may be grouped together in a way that obscures local velocity perturbations. For example, Verghese and Stone (1995, 1996) found that speed discrimination was worse for a single large patch than for multiple small patches, even though the total stimulus area was the same in the two cases. This finding suggests that bringing motion elements into close proximity impairs speed discrimination. From their work on the detection of trajectories in noise, Watamaniuk, McKee, and Grzywacz (1995) suggested that similar motion signals are grouped along a smooth motion path. More recent work has shown that motion signals are not strictly combined, but that the initial motion segment cues subsequent motion in the vicinity (Verghese & McKee, 2002). Are these integration or grouping processes obligatory or do they instead reflect expectations about naturally occurring motions?

Objects in motion rarely change direction and speed abruptly. Based on past visual experience, we expect objects in motion to continue along their trajectories without abrupt changes in speed (Weiss, Simnocelli, & Adelson, 2002). Thus, the visual system may treat local

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velocity changes as noise to be ignored, even if detected. If so, this 'prior' for smooth velocity could be overridden by experience or training that made the acceleration task-relevant. In this study, we examine how the spatial layout of velocity signals affects the ability to discriminate velocity differences. We shall also explore the role of practice in detecting velocity changes.

Consider the case when an observer has to discriminate the speed of moving dots in two halves of a circular display. In Fig. 1A, the dots move parallel to the boundary, while in Fig. 1B they move orthogonal to the boundary such that the dots appear to continue across the boundary. Our prediction is simple. If perception is influenced by prior experience with objects in motion that do not change speed or direction abruptly, then speed differences will be harder to discriminate in the case when motion crosses the boundary than when motion is parallel to the boundary.

Our experimental design is well suited to examining both segmentation effects due to motion parallax and integration effects that are thought to interfere with the detection of acceleration. With a 90° rotation of motion direction with respect to the boundary, we can go from the parallel condition that favors segmentation due to motion parallax (Mestre, Masson, & Stone, 2001) to the orthogonal condition that appears to favor integration. This latter condition is equivalent to the dots undergoing an acceleration or deceleration at the boundary. Several studies (Nakayama, 1985; Snowden & Braddick, 1991), have suggested that the visual system is not sensitive to detecting acceleration because local signals are integrated over time. Here, we show that while observers are initially poor at detecting speed differences in the orthogonal (acceleration) condition, they learn to access the local signals with practice. These results argue in favor of observers modifying their prior, rather than a compulsory integration process.

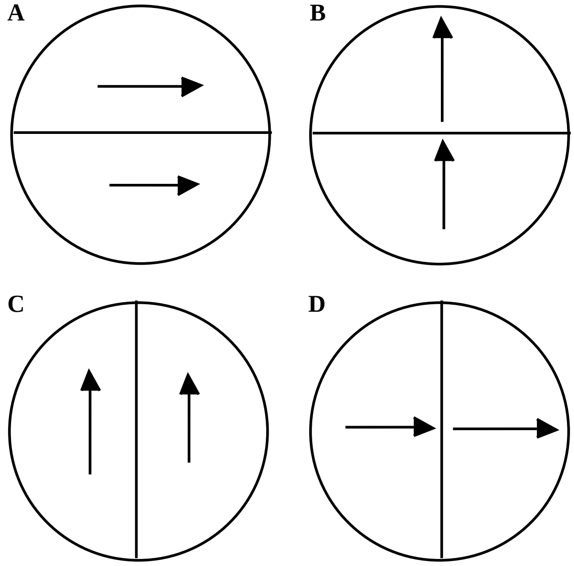

Fig. 1. The four possible stimulus configurations. (A) An invisible horizontal border divides the display into two halves and motion is horizontal, i.e., parallel to this border. The direction of motion is randomly left or right in each trial and both halves move in the same direction. (B) The border is horizontal and motion is vertical, orthogonal to the border. The motion direction is either up or down in both halves. In (C and D) the border is vertical. Motion direction is vertical and parallel to the border in (C) and horizontal and orthogonal to the border in (D).

2. Methods

We used a circular display of radius 6°. The display was split along a horizontal midline as described above. We also added conditions where it was split along a vertical midline (Figs. 1C and D). The dividing line was never physically present, although observers had full knowledge of its orientation in Experiments 1 and 2. The moving dots had different speeds on either side of this midline. Dots moved either parallel to the boundary, or orthogonal to the boundary appearing to continue across the border. In Experiment 1, the dividing line was always horizontal, which meant that dot motion was horizontal in the parallel condition and vertical in the perpendicular condition. To control for the possibility of differential sensitivity to horizontal vs. vertical motion, the dividing line in later experiments was either horizontal or vertical. Thus, the orientation of the dividing line and the parallel vs. orthogonal condition determined the direction of the dots. For a display divided along the vertical midline in these later experiments, dots moved in the vertical direction in the parallel case, and moved in the horizontal direction in the orthogonal case. The converse was true for a display divided along a horizontal midline. Each of these four conditions was run in separate blocks. In a given block with say horizontal motion parallel to a horizontal border, the dots all moved to the left or to the right, so that their motion was not predictable from trial to trial. Similarly, the dots moved randomly up or down in conditions with vertical dot motion.

The duration of the display was 200 ms, which at the 71 Hz frame rate of the monitor, corresponded to 14 frames of the stimulus. The base speed of the dots was 12°/s. When dots left the circular stimulus region, they wrapped around. One-half of the display, picked at random, was assigned the base speed, and the other half was assigned the speed increment. Observers were asked to pick the half with the faster speed. Feedback was provided. Proportion correct in this spatial two alternative forced-choice (2AFC) task was plotted as a function of speed difference.

Typically, the display contained 400 dots, divided equally between the two halves. We also performed additional experiments where half the dots in the display were substituted by noise dots in Brownian motion.