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Dissociable factors affect speed perception and discrimination

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Abstract

Factors affecting our judgement of the speed of visual motion were investigated. Two types of judgement were made: perceived speed relative to a standard comparison stimulus, and discrimination between the speeds of similar stimuli. The factors affecting these two judgements were found to be doubly dissociable, suggesting that they may be constrained by processing at different levels of the visual hierarchy. The results are discussed in terms of the 3-D interpretation of visual image motion, and related to possible neural substrates.

Key words: complex motion, motion perception, speed discrimination.

Introduction

Image motion is a fundamental source of information for identifying objects and navigating through the environment.[1] Neurons sensitive to motion exist early in the visual pathway. The response of many of these neurons is tuned to the speed at which the image moves across the retina.[2] Later mechanisms have more complex receptive field properties, such as selectivity for global patterns of motion.[3–5] Global patterns of retinal motion typically result from movements of the observer's own head and eyes, or from walking, running or driving. Recent studies have shown that the perceived speed of complex motions depends upon the global pattern of motion, with expanding patterns of motion typically appearing faster than corresponding rotations or translations.[6–9] This appears to be a robust finding, having been demonstrated with stimuli moving at a range of speeds extending from 2.0°/s to 21.3°/s,[7,9] and with stimuli that did[9] and did not[7,8] contain a speed gradient. This tells us that speed perception is not mediated purely by early mechanisms. It has also been demonstrated that the difference in speed necessary for a subject to discriminate between the faster moving of two similar stimuli depends upon the way in which the image is partitioned. Specifically, it has been demonstrated that increasing the size of a single drifting sinusoidal grating does not enhance the ability to discriminate speed, whereas increasing the number of independent gratings is beneficial.[10] Here we show that these contextual effects on speed perception and discrimination are doubly dissociable. Manipulating the global pattern of motion has an influence on perceived speed without affecting discrimination thresholds.[8,9,11] Increasing the number of perceptually discrete objects within the stimulus improves speed discrimination performance,[9] but does not affect perceived speed. These results suggest that performance on tasks as closely related as the perception and discrimination of a single stimulus attribute can be constrained by processing at different levels of the visual hierarchy.

Methods and Results

We presented subjects with pairs of stimuli in two temporal intervals and asked them to report which stimulus appeared to be moving faster. Three types of stimulus were used: (i) 4-patch translational motion; (ii) 2-patch translational motion; and (iii) 4-patch radial motion (Fig. 1a–c). Presenting dissimilar stimuli allowed us to measure the perceived speed of the 2-patch translation and the 4-patch radial stimuli relative to the 4-patch translation. Presenting similar stimuli in the two intervals allowed us to measure the difference in speed necessary for discrimination between each of the stimulus types. Results for two of the authors and for a group of 12 naive subjects are shown in Fig. 2. In all cases the perceived speed of the radial stimulus was significantly greater than that of the 4-patch translation, whereas the perceived speeds of the 2- and 4-patch translations were not significantly different. Speed discrimination thresholds were not significantly different for the 4-patch stimuli, but performance was significantly worse with only two patches.

Discussion

These results are indicative of a double dissociation between the processes of speed discrimination and perception. The enhanced perceived speeds of radial patterns of motion were not reflected in increased discrimination thresholds, suggesting that speed discrimination performance is limited by early mechanisms with less complex computational properties

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Figure 1. Stimulus configurations for (a) 4-patch translation, (b) 2-patch translation, and (c) 4-patch expansion. Stimuli were presented on a computer monitor with a mean luminance of 37.4 cd/m^2 and a refresh rate of 120 Hz. All gratings had a spatial frequency of 1.0 c/d and a peak contrast of 40%, and were presented in windows with a gaussian space constant of 1.0° (4-patch) or 1.4° (2-patch), and a mean eccentricity of 5.5° (subjects CC and DA) or 4.5° (naive subjects). The gratings within each stimulus patch in a given temporal interval moved at the same speed. A trial consisted of two intervals of 250 msec, separated by a blank interval of 2 s. In one interval, the gratings moved at the reference speed of 10°d/s. In the other interval, stimulus speed was selected under computer control using the method of constant stimuli. Subjects were required to report in which interval the gratings appeared to be moving faster. Perceived speeds and discrimination thresholds were obtained from fits of a psychometric function to each subject's response data in each stimulus condition.

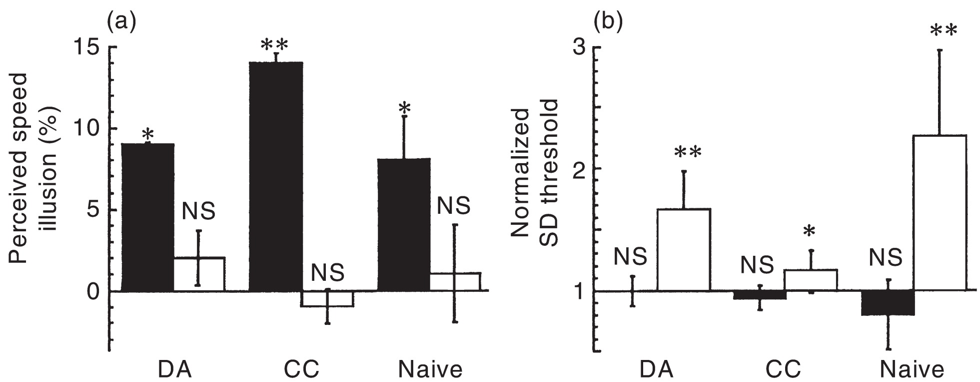

Figure 2. (a) Magnitude of the perceived speed illusion measured against the 4-patch translation for subjects CC and DA and a group of naive subjects (n = 12). Dark bars represent the results for 4-patch radial motions (expansions for CC and DA; contractions for the naive subjects), light bars for 2-patch translations. In all cases, the perceived speed of the 2- and 4-patch translations was not significantly different, while radial motion appeared significantly faster than the translations (**$P < 0.01$ for CC; *$P < 0.05$ for DA and the naive subjects). (b) Speed discrimination thresholds for 4-patch radial motion (dark bars) and 2-patch translation (light bars) expressed as a fraction of the thresholds for 4-patch translation. In all cases, discrimination thresholds for 4-patch radial and translational motion were not significantly different. Discrimination thresholds for the 2-patch stimulus were significantly higher than the pooled thresholds for the 4-patch stimuli (**$P < 0.01$ for DA and the naive subjects; *$P < 0.05$ for CC).

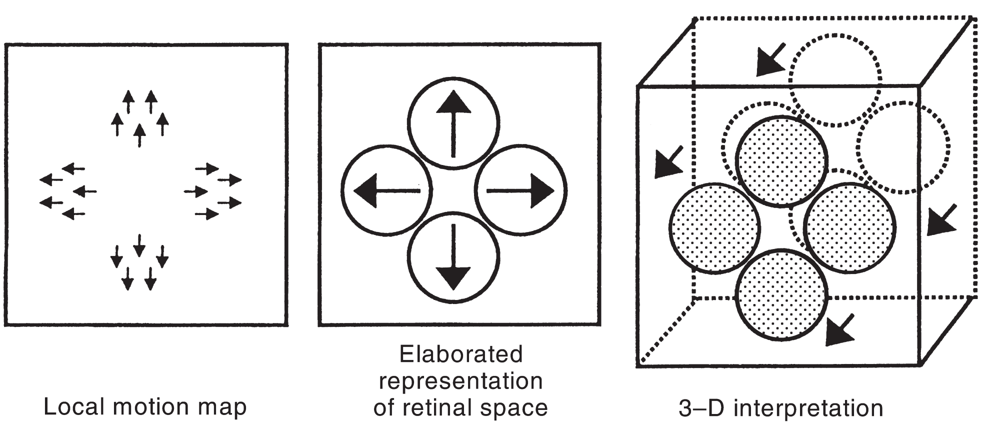

Figure 3. Schematic diagram of the functional architecture proposed to underlie the perception of speed.

than relatively later mechanisms that mediate the perception of speed. The improvement in speed discrimination performance with increasing number of stimulus patches further suggests that the responses of early speed-tuned mechanisms feed into a representation of the visual scene in which only one independent estimate of speed is computed per perceptually discrete object.[10]

Radial patterns of motion typically result from the observer's own motion through the environment.[12] Radial patterns of motion presented on a computer screen can also induce a perception of motion-in-depth. The sensation of motion-in-depth accompanying radial motion has been linked to the effect of motion pattern upon perceived speed.[7–9] If judgements of speed are based upon perceived motion in a 3-D environment, rather than on 2-D retinal projection, then different patterns of motion will give rise to differences in perceived speed consistent with their perceived 3-D trajectories.

The inferred functional architecture underlying speed perception is illustrated schematically in Fig. 3. The local motion map of early speed-tuned responses feeds into an elaborated description of retinal space,[13] which in turn supports a representation of 3-D motion and depth. The interdependence of motion and depth cues found here is consistent with recent electrophysiological studies reporting tuning for both speed and binocular disparity in region MT, the 'motion centre' of the primate visual cortex.[14,15] It should be possible to test neurophysiologically whether extra-classical receptive field effects at this level underlie the interactions between distant stimulus patches which are reported here.

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