Supplemental Information

Separation in the visual field has divergent effects on discriminating the speed and the direction of motion

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Supplemental Materials and Methods.

Observers. There were 10 participants in the experiment (4 males), all right-handed and all with normal or corrected-to-normal visual acuity. Three were authors of the paper and were highly trained on similar psychophysical tasks. The others were naïve as to the purpose of the experiment. The study was approved by the Psychology Research Ethics Committee of Cambridge University and all participants gave informed consent before taking part.

Apparatus and stimuli. Stimuli were presented on a 22-inch CRT monitor (Mitsubishi Diamond Pro 2070), set to a spatial resolution of 1024 x 768 pixels and a frame rate of 100 Hz. The display was controlled by a CRS (Cambridge Research Systems, Rochester, Kent, UK) graphics board, model VSG2/5. The monitor outputs were linearized with a silicon photodiode, and the spectral output of each gun at maximum was measured by a JETI spectroradiometer (model Specbos 1201; Jena Technische Instrumente, Jena, Germany).

A steady neutral background (of luminance 10 $cd.m^{-2}$ and metameric to Illuminant D65 [S1]) was always present on the screen. A matte black mask with circular aperture was mounted in front of the display to minimize vertical and horizontal cues from the environment. The experiment was conducted in a dark room, lit only by light from the exposed part of the monitor face. Viewing was binocular from a chin-rest at a distance of 114 cm.

Each presentation consisted of two briefly presented arrays of pseudo-random moving dots. The arrays fell on an imaginary circle of radius 5 degrees of visual angle, centred on the fixation point. Each array had the form of a sector of an annulus and was 2° wide at its midpoint. The spatial separation of the midpoints of the two arrays could vary, in different blocks of trials, from 2° (when their edges touched) to 10° (when they lay on a diameter of the imaginary circle). Although they were yoked in this way, their joint position fell randomly on the imaginary circle from trial to trial, so that the participant could not anticipate their positions. When the spatial separation was 10°, the two arrays fell in opposite hemifields on most trials.

The arrays consisted of red or green dots, colour being used only to allow a clear perceptual segregation of the arrays when they were juxtaposed [S2]. Each dot was constructed as a square of 4 x 4 pixels and subtended 4.26 angular minutes at the eye. The CIE_{1931} chromaticities [S1] were x,y = 0.626, 0.340 for red dots and 0.294, 0.607 for green. Their luminance in both cases was 38 $cd.m^{-2}$. The dots were anti-aliased to allow displacements of less than 1 pixel between frames.

The method of constructing each array of dots was as follows. Firstly, we generated a regular array of dots separated by 25 pixels (26.6 angular minutes). Each dot position was then randomly jittered within its cell. Two such arrays were created, one for red dots, one for green. The full screen was filled with the conceptual array, and every dot was displaced between frames to give the required direction and speed, but only dots located within the specified sector were displayed on a given presentation. To maintain the overall density of dots, a new dot was generated at a mirror-image position on the screen whenever a dot died anywhere within each conceptual array.

Procedure. Thresholds for discrimination were measured by a two-alternative temporal forced-choice method. In one of two 180-ms presentations, separated by 500 ms, the two arrays moved in the same direction at the same speed. In the other presentation, chosen at random, the arrays differed in speed or in direction, according to the condition being tested. The participant's task was to report in which presentation a difference was present and auditory feedback was given after each response. This psychophysical method allows the experimenter to study a same-difference judgement but to sidestep any bias towards the response 'same' or the response 'different'. It was used by Mollon and Cavonius [S3] to measure thresholds for discrimination of wavelength. It is a comfortable task for the observer, but results in higher thresholds, since the judgement is based on four external stimulus samples, each with its own variance, rather than the two samples that are compared in a traditional two-alternative spatial forced choice. The stimuli used to measure speed in the present experiment are very similar to those we previously used in a two-alternative spatial forced choice [S2], but the measured thresholds are higher.

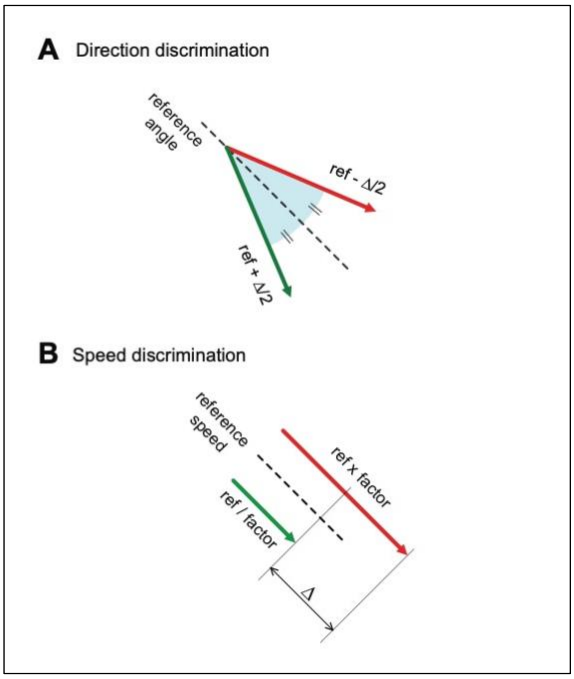

Figure S1: Legend.

Illustration of the 'straddling' procedure for measuring thresholds. The reference angle (**A**) or the reference speed (**B**) is never presented. In the case of direction discrimination, in the presentation in which the directions of the arrays differed, one array took the direction (referent +Δ/2 deg) and the other took the direction (referent -Δ/2 deg). Thresholds were expressed as the average value of Δ on the last 10 reversals of the staircase. In the case of speed discrimination, in the presentation in which the arrays differed in speed, one array moved with the reference speed multiplied by a factor and the other array moved with the reference speed divided by the factor. Thresholds were expressed as the average value of the factor on the last 10 reversals.

The stimulus values on a given trial were determined by a 'straddling' procedure (such as we have previously used to measure colour discrimination [S4]).

In the direction discrimination task, the speed of all dots was fixed at 5 deg.s^{-1}. The referent direction was set to be 135° clockwise from vertical (i.e. south east or 4.30

o'clock. Figure S1), but this direction was never in fact presented. The test directions straddled the referent direction by ±Δ/2 deg (see Figure S1 A). In the presentation in which the directions of the arrays differed, one array took the direction (referent +Δ/2 deg) and the other took the direction (referent -Δ/2 deg). In the presentation in which the directions of the arrays were the same, the direction was not the reference direction. Instead, both arrays took the direction (referent +Δ/2 deg) or the direction (referent -Δ/2 deg), the choice being random. This arrangement ensures that the participant cannot solve the task simply by attending to the direction of only one array in each presentation and comparing it to a learnt internal template of the referent direction – a strategy that may otherwise be remarkably efficient in comparison tasks [S5–S8]. Δ was adjusted adaptively to measure the threshold (see below).

In the speed discrimination task, all dots moved in a south east (4.30 o'clock) direction and the reference speed, relative to which thresholds were measured, was 5 deg.s^{-1}. To prevent path-length being used as a cue to speed, dots within each array had a limited lifetime and the mean path-length was constrained to remain constant as speed varied. (Specifically, in both the speed and the direction experiments, the mean path-length of each individual dot was randomly jittered around the mean, so that its actual value in pixels corresponded to the distance travelled by the reference speed in 9±6 frames.) The reference speed was never itself presented. In the presentation in which the arrays differed in speed, one array moved with the reference speed multiplied by a factor and the other array moved with the reference speed divided by the factor (see Figure S1B); and this factor was adjusted adaptively to measure the threshold (see below). In the presentation in which the speeds of the arrays were the same, their common speed was not the reference speed but was randomly chosen to be either the reference speed multiplied by the current factor or the reference speed divided by the factor

In the case of direction, we adopted the same absolute increment and decrement relative to the referent (i.e. Δ/2) , since this dimension is metathetic, in the sense introduced by S. S. Stevens [S9], and there is no *a priori* reason to expect sensitivity to vary asymmetrically around the referent. In contrast, speed is prothetic; and in the region of 5 deg.s^{-1}, Weber's law is known to hold approximately [S2, S10]. Hence, we used a factor in this case.

Thresholds were measured adaptively using a three-down/one-up staircase procedure tracking 79.4% correct [S11]. In the case of direction, the initial value of Δ was 20°, and in the case of speed, the initial value of the multiplying factor was 1.25. These values were increased or decreased by 10% when required by the staircase rule. Staircases terminated after 15 reversals. The last 10 reversals were averaged to estimate the threshold.

One experimental run contained 8 blocks of trials and different spatial separations were tested in different blocks, in random order. Runs devoted to speed and to direction were interleaved. Six independent estimates of each threshold were collected over the course of several experimental days. The first measurement of each threshold was treated as practice and so our analyses are based on the last 5 measurements.

Supplemental References

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