Vision Res. Vol. 33, No. 14, pp. 2013–2019, 1993
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0042-6989/93 $6.00 + 0.00

Research Note

Dependence on Stimulus Onset Asynchrony in Apparent Motion: Evidence for Two Mechanisms

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Received 17 September 1992; in revised form 4 February 1993

The detection of the direction of motion was measured as a function of the spatial and temporal offset for a kinematogram stimulus presented in two-frame apparent motion. The stimulus was made up of Gabor function micro-patterns randomly distributed across the stimulus field. We show that for short stimulus onset asynchronies (SOA) performance can be predicted from the spatio-temporal Fourier power spectrum of the stimulus, whereas for long SOAs the pattern of performance is qualitively different from such a prediction. The dependence of motion perception on SOA exhibits an abrupt change from one mode of behaviour to the other. These findings are suggestive of the operation of distinct mechanisms, one "quasi-linear" and one "nonlinear", which can be separated by temporal parameters.

Apparent motion   Stimulus onset asynchrony   Fourier analysis

INTRODUCTION

There are several reports in the literature suggesting two processes for the detection of motion (Braddick, 1974, 1980; Anstis, 1980; Chubb & Sperling, 1988; Petersik & Pantle, 1979), with differential spatial and temporal sensitivities. The evidence for two processes for the detection of motion presented by Petersik and his colleges used a Ternus display which gives a bistable percept that they manipulated by varying the parameters of the stimulus (Petersik, 1991; Petersik & Pantle, 1979). Despite the evidence from the Ternus display, a major criticism of the proposed dichotomies is that, the two processes hav been characterized with the use of different stimuli (Cavanagh & Mather, 1989) and consequently could be recast in terms of a stimulus dichotomy rather than a qualitative difference in underlying mechanism.

We have developed a single stimulus which has allowed us to reveal two distinct modes of behaviour, dependent on quantitative values of stimulus parameters. We constructed a stimulus in which many identical *micro-patterns* are randomly positioned throughout the stimulus field. These micro-patterns are narrow-band in both spatial frequency and orientation, in keeping with evidence that the motion system processes information via orientated, spatial frequency selective channels (Pantle, Lehmkuhle & Caudill, 1978; Turano & Pantle, 1985; DeValois, Albrecht & Thorell, 1982; Baker & Cynader, 1986; Boulton & Hess, 1990; Cameron, Baker & Boulton, 1992). This form of stimulus construction also provided the opportunity to independently manipulate local stimulus attributes such as the *size* (spatial extent) and *density* of the stimulus features (micro-patterns). Previously we have dissociated the role of size and spatial frequency for the maximum limit (D_{max}) for the detection of motion (Boulton & Baker, 1991), showing that D_{max} is dependent on the *spatial frequency* content of the stimulus elements and not their size. However, this dependence on the frequency content *only* occurs when the stimulus is comprised of many elements, i.e. densely populated; when the stimulus is *sparsely* populated, performance is dependent on the *density* of the elements, irrespective of their frequency content (Boulton & Baker, 1992, 1993). The abrupt discontinuity in D_{max} as a function of micro-pattern density suggests two underlying mechanisms, one that behaves in a "quasi-linear" manner, and a second that is clearly "nonlinear".

Here we investigate the dependence of motion detection on the temporal parameters of a two-flash apparent motion stimulus. We use a random Gabor kinematogram as described above and manipulate the stimulus onset asynchrony (SOA) between the first and second frames of the apparent motion sequence. We present evidence that motion can be reliably detected from two frame apparent motion across a long temporal interval, but that the underlying mechanism is qualitatively different from that for short temporal intervals. For short SOAs performance is predictable from the information in the spatio-temporal Fourier power spectrum of the stimulus, consistent with a spatio-temporal linear mechanism; whereas performance for long SOAs is entirely unrelated to the power spectrum, clearly indicating qualitatively nonlinear behaviour.

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METHOD

The experiments were performed on two very similar set-ups, henceforth referred to as "Montreal" and "Utrecht". The stimuli were generated using a Compaq 386 (Montreal) or a Philips 286 (Utrecht) micro-computer, both fitted with Number Nine Corporation graphics cards (Revolution 1024). The stimuli were displayed on Joyce Electronics DM2 CRT display monitors which were synchronized to the graphics card. The monitors had white phosphors (P4), one (Montreal) had a mean luminance of 360 cd/m^2, a refresh rate of 200 Hz and a spatial resolution of 256 × 512 for a screen of 23 × 30 cm, while the second monitor (Utrecht) had a mean luminance of 240 cd/m^2, a refresh rate of 100 Hz and a spatial resolution of 256 × 1024 for a screen of 23 × 30 cm (i.e. the screen in Utrecht had twice as many lines across its width, 30 cm). The internal z-axis linearization of the display monitors was confirmed with a Hagner Universal Photometer for the range of contrasts used.

The stimuli consisted of micro-patterns distributed semi-randomly across the visual field. The micro-pattern was a Gabor function, that is a one-dimensional sine-wave grating multiplied by a two-dimensional Gaussian window:

$$L(x, y) = L_0\{1 + C \exp[-(x^2/2\sigma_x^2 + y^2/2\sigma_y^2)] \cdot \cos(2\pi x/\lambda + \phi)\} \quad (1)$$

where L_0 = mean luminance; C = contrast; σ_x = horizontal Gaussian width parameter; σ_y = vertical Gaussian width parameter; λ = wavelength of the cosine wave; ϕ = phase of cosine wave.

For the kinematogram stimulus used in these experiments, the Gabor function micro-patterns were of spatial frequency 2.25 c/deg, with a σ of 0.75λ ($\sigma_x = \sigma_y$). The phase was always even symmetric. The micro-patterns were placed in two strips across the top and bottom of the stimulus field so as to confine the stimulus in eccentricity and to prevent the observers from paying attention to a fortuitous stimulus "feature" (e.g. a relatively isolated micro-pattern) close to the fixation mark. The stimulus strips were placed about 4 deg above and below the fixation mark, and contained 66 micro-patterns; an example is shown in Fig. 1. On each trial, micro-patterns were placed on a notional grid of 11 columns and 3 rows in each strip; each micro-pattern position was randomly "jittered" by one-third of the grid spacing about the grid location, to prevent periodicity effect. Values of positional jitter were independently selected each trial for each micro-pattern. The stimuli had a maximum contrast of 14 dB of attenuation (20% contrast), with contrast (C) defined as $(L_{\max} - L_{\min})/L_{\max} + L_{\min})$. Stimuli were rendered to 8 bits of grey scale, and then analogue attenuation was used to produce lower contrasts. The stimulus field of randomly distributed micro-patterns was presented in one position for 100 msec (20 frames at 200 Hz or 10 frames at 100 Hz), then displaced by a specific number of pixels to either the left or the right (with wrap-around at the display boundaries), and presented for another 100 msec in the new position. Whenever there was no stimulus present, (including the inter-stimulus interval when the SOA exceeded 100 msec) the stimulus field was of mean luminance, L_0. If the two stimulus presentations overlapped (i.e. the SOA was < 100 msec) then the

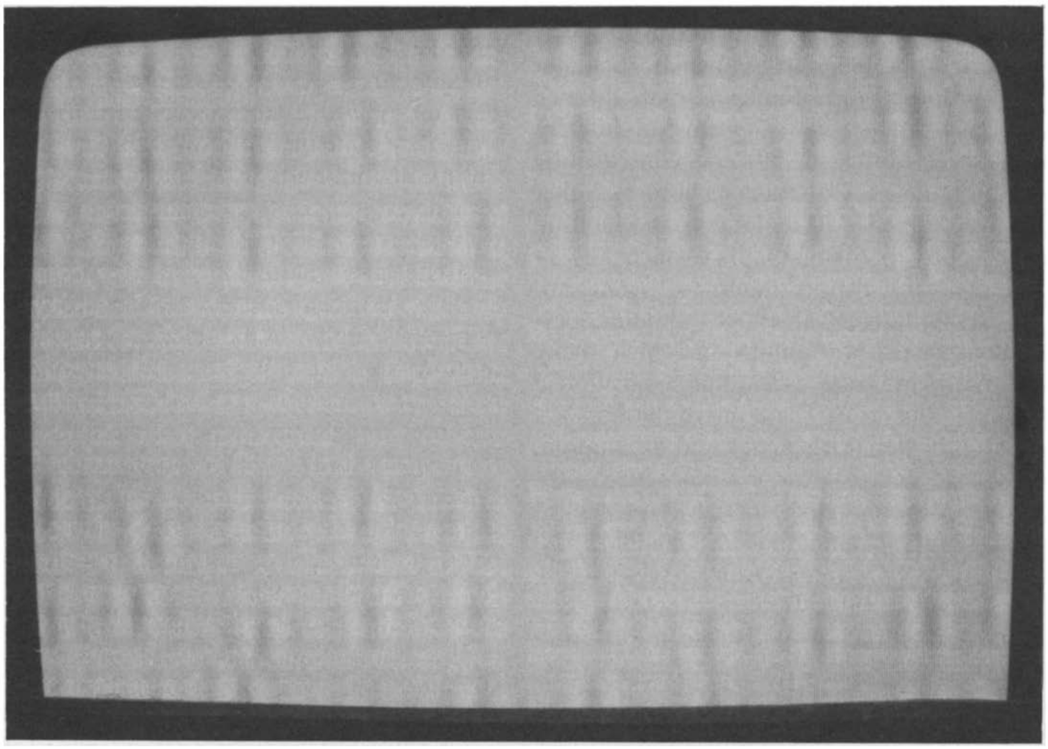

FIGURE 1. A photograph of one frame of the stimulus. Gabor micro-patterns are distributed in two strips above and below the fixation mark in a pseudo random manner.