Psychol Res (1983) 45:11–18

Psychological Research

Short- and Long-Range Processes in Visual Apparent Movement

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Summary. The minimum stimulus-onset asynchrony required for perception of beta apparent movement was measured with point stimuli separated by visual angles ranging from about 0.1° to 5° and viewing distance as a parameter. For each viewing distance, the threshold for beta movement was a monotonic function of the visual angle with a strong linear increase over angles less than 0.25° (short-range function) and a much weaker linear increase over angles greater than 1.5° (long-range). The short- and long-range functions were differentially affected by increase in viewing distance: the long-range function increased in slope, but the extrapolated zero-intercept was constant; the short-range function changed in intercept, but not in slope. The results provide strong evidence for separate short- and long-range processes in visual motion perception.

Introduction

Anstis (1978, 1980) and Braddick (1974, 1980) developed a two-process theory for visual perception of apparent movement. In this theory, a *short-range* process, tentatively identified with the response of directionally selective neurons in the visual system (see, e.g., Grüsser and Grüsser-Cornehls 1973), subserves perception of apparent movement with small spatial displacements (about 0.25° or less) and small temporal intervals (100 ms or less) between successive stimuli. The short-range process produces motion aftereffects (cf. Anstis and Cavanagh 1981; Banks and Kane 1972), but it fails to operate dichoptically (Braddick 1974), and it fails with stimulus patterns defined by chromatic but not luminance contrast (Ramachandran and Gregory 1978). Outside the limited domain of the short-range process, apparent movement should be signalled by a higher-level, *long-range* process. The long-range process tolerates spatial displacements of many degrees (e.g., Zeeman and Roelofs

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1953) and long interstimulus intervals (ISIs up to at least 300 ms; Neuhaus 1930). Motion aftereffects are weak (Anstis and Moulden 1970) or absent (Banks and Kane 1972), but the process may be driven dichoptically (Shipley et al. 1945), and it works with patterns defined by chromatic contrast alone (Ramachandran and Gregory 1978).

The two-process theory has so far been based on experiments with rather complex stimulus displays. Braddick's (1974) original description of the short-range process was derived from observations on perceptual segregation by coherent movement of uniformly displaced regions in alternated pairs of random-dot patterns (Anstis 1970; Braddick 1973, 1974; Julesz 1971). Many later studies (Braddick and Adlard 1978; Pantle and Petersik 1980; Pantle and Picciano 1976; Petersik and Pantle 1979) have used a bistable motion display devised by Ternus (1926), tentatively associating the short- and long-range processes with the stable states of the display (see Ullman 1979, for a critique). The present investigation was undertaken to determine if the proposed distinction between short- and long-range processes could be established by exploration of the spatiotemporal parameters of a simple, classical stroboscopic motion display consisting of two alternating point sources.

Consider the classical studies of alleged long-range apparent movement. Most investigations of spatiotemporal parameters used successive presentation of two isolated spots separated by a visual angle of at least 0.5°. Korte (1915) explored a spatial range from 1.75° to nearly 15°. He conjectured that, when stimulus intensity and duration are kept constant, the ISI required for apparent continuous movement of an object (*beta* movement) is directly related to the spatial separation between the stimuli (Korte's third law). The conjecture is famous, but it is not tenable as it stands. Parametric data by Caelli and Finlay (1979, 1981), Caelli et al. (1978), Finlay and Caelli (1979), and Neuhaus (1930) indicate that if a given ISI provides beta movement over a given spatial separation, it provides beta movement over any smaller separation, too. This relationship implies that, first, it cannot be the case that increase in ISI requires increase in spatial separation in order to preserve beta movement; second, it is not always the case that increase in spatial separation requires increase in ISI. Nevertheless, Korte's third law does appear to embody an important principle. The cited studies suggest that when stimulus intensity and duration are kept constant, the minimum ISI required for beta movement (the "simultaneity threshold"; Corbin 1942) increases with the spatial separation.

Qualifications on the effective parameters are needed. First, Corbin (1942) varied the retinal separation between stimuli independently of their separation in physical 3-D space by changing the slant of the screen on which his stimuli were positioned; he found that the temporal threshold for apparent movement depended upon the physical separation with no effect of retinal separation per se. In a related study by Attneave and Block (1973), goodness of apparent movement was determined jointly by retinal separation and physical separation in 3-D space. It seems safe to conclude that the apparent distal separation between stimuli in 3-D space is a critical spatial parameter for apparent movement.[1]

1 Findings from more complex paradigms (competing motion technique; Ullman 1979) provide a contrast: For processes selecting among competing paths of movement, only 2-D separation seems relevant (Ullman 1978)

Second, early investigators (Korte 1915; Wertheimer 1912) stressed the import of the ISI for apparent movement. Later studies (e.g., Caelli et al. 1978; Kahneman 1967; Kahneman and Wolman 1970; Kolers 1964; Neuhaus 1930; Sgro 1963) showed strong trade-off between stimulus duration and ISI.[2] Thus, unless there is temporal overlap between the stimuli, the stimulus-onset asynchrony (SOA) appears to be the most critical temporal parameter near the simultaneity threshold for apparent movement.

Experiments 1 and 2

In the current experiments, we presented subjects with two point sources in continuous sequential alternation, with zero ISI and zero intercycle interval, and measured the minimum SOA required for beta apparent movement as a function of the angular separation of the sources (cf. Saucer 1953, 1954; Tyler 1973; Zeeman and Roelofs 1953; see also Bundesen et al. (in press); Farrell et al. (1982); Shepard and Judd 1976). Spatial displacements ranged from about 0.1° to 5° and viewing distance was varied as a parameter. Would the action of the hypothetical short-range process be reflected in the threshold functions?

Method

Subjects. Our subjects were students or members of the staff at Copenhagen University. They were paid by the hour. All had normal or corrected-to-normal vision.

Stimuli and Apparatus. The subjects were individually presented with a frontal setup containing a horizontal array of small (2.5 mm in diameter) red diodes. A green (5 mm in diameter) diode with a steady luminous intensity of approximately 7×10^{-5} cd, always elevated 1° above the midpoint of the array of red diodes, served as a fixation point. On each trial two of the red diodes, symmetrically located with respect to a vertical plane through the line of sight, were lit in sequential alternation without any blank interstimulus interval. The intensity of a lit red diode was approximately 3×10^{-4} cd. The subject viewed the display binocularly, with head position constrained by a chin rest. The ambient illumination in the region of the stimulus display was about 0.02 lx, so the region was dimly visible.

Procedure. At the beginning of a trial, the SOA between the active red diodes was set to 1500 ms. At this rate of alternation, the pair of stimuli produced a visual illusion of a single spot of light continuously moving back and forth between the stimulus locations. By pressing a key, the subject could decrease the SOA by 1/11. The

2 This trade-off between stimulus duration and ISI is sometimes referred to as the fourth law of Korte (e.g., Graham 1965). Korte (1915) did conjecture that the ISI required for beta movement is inversely related to the duration of stimulus exposure, but he claimed that "a change in exposure time has a relatively small effect on the appearance as compared to a change in the pause" (p 268; our translation)

subject was instructed to press this key repeatedly until the illusion of apparent continuous movement of a single luminous spot (beta movement) disappeared (to be replaced, for example, by perception of partial movement or flicker). The setting, SOA1, was recorded. The subject was instructed to then press a second key which increased SOA by tenths, until beta movement was reestablished.[3] The new setting, SOA2, was also recorded.

Design. In Experiment 1, viewing distance was 6 m and the visual angle between the active red diodes was either 0.095°, 0.153°, 0.21°, 0.25°, 0.41°, 0.56°, 0.8°, 1°, 1.5°, 2°, 3°, 4°, or 5°. For each subject (n = 3), the angles were tested once in each of 15 blocks of trials. Within blocks, the order of presentation was randomized.

In Experiment 2, viewing distance was either 1.5 m or 6 m. With the 1.5-m viewing distance, the stimulating diodes were separated by a visual angle of about 0.095°, 0.153°, 0.191°, 0.248°, 2°, 3°, 4°, or 5°. With the 6-m viewing distance, the angular separation of the stimuli was 0.095°, 0.134°, 0.191°, 0.244°, 2°, 3°, 4°, or 5°. The subjects (n = 9) ran 10 blocks of trials at each viewing distance such that viewing distance was changed after each block. The angles were tested once per block in random order.

Results

The results of Experiment 1 are presented in Fig. 1. Over the entire range of visual angles investigated, the minimum SOA required for beta apparent movement, measured as the average of SOA1 and SOA2 means, increased with angular separation. For apparent movement over visual angles of 0.25° or less, the threshold function was approximately linear with least squares slope and zero-intercept at 265 ms/deg and 99 ms. For movement over visual angles of 1.5° or more, the funtion was again approximately linear with a slope of 18.0 ms/deg and an intercept of 230 ms.

The results of Experiment 2 are shown in Fig. 2. For either of the two viewing distances, the minimum SOA required for beta movement increased with angular separation, and the function was approximately linear in the range of small visual angles (i.e., angles less than 0.25°) and, again, in the range of large visual angles (i.e., angles of 2° or more). Increasing the angular separation from 0.1° to 0.25° increased the movement threshold by about 25 ms, whether viewing distance was 1.5 m or 6 m, but the level of the short-range threshold function was 22 ms higher for the longer viewing distance (Fig. 2A). Increasing the separation from 2° to 5° increased the movement threshold by 44 ms with a viewing distance of 1.5 m, and 70 ms with viewing distance 6 m, but the extrapolated zero-intercept of the long-range function showed no increase with viewing distance (Fig. 2B). The short- and long-range functions were thus differentially affected by changes in viewing distance.

Chi-square tests indicated no significant departures from linearity in any of the short- and long-range functions of the two experiments (in each case, $P > 0.5$). t-Tests applied to slopes and zero-intercepts of least-squares lines fitted to data for

3 For analysis of other types of movement experienced in comparable experimental conditions, see Tyler (1973) and Zeeman and Roelofs (1953)

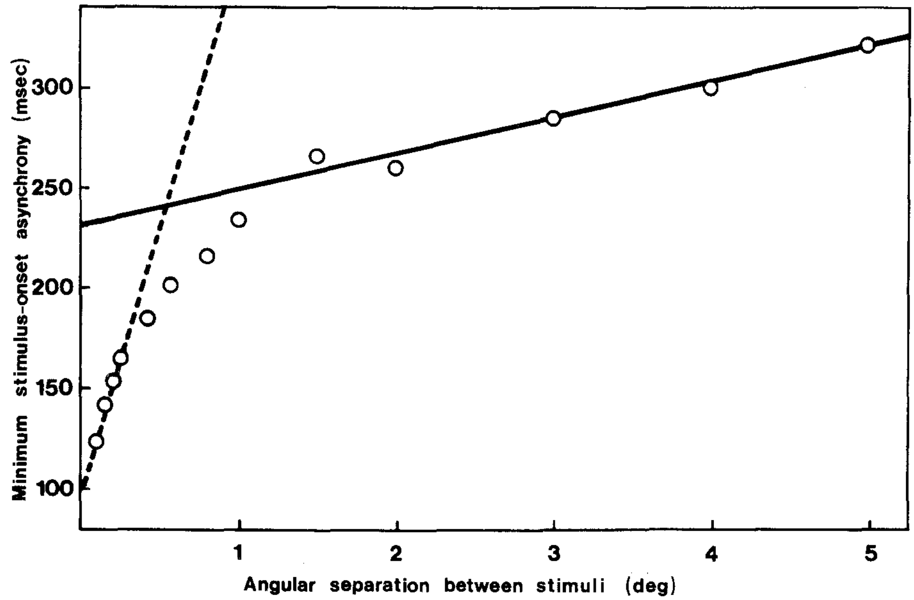

Fig. 1. Minimum stimulus-onset asynchrony required for perception of apparent movement (averaged across subjects) as a function of the visual angle separating the stimuli (Experiment 1). Estimated standard errors ranged between 3 ms and 7 ms. Separate least-squares straight lines have been fitted to the data for small (≤ 0.25°) and large (≥ 1.5°) visual angles.

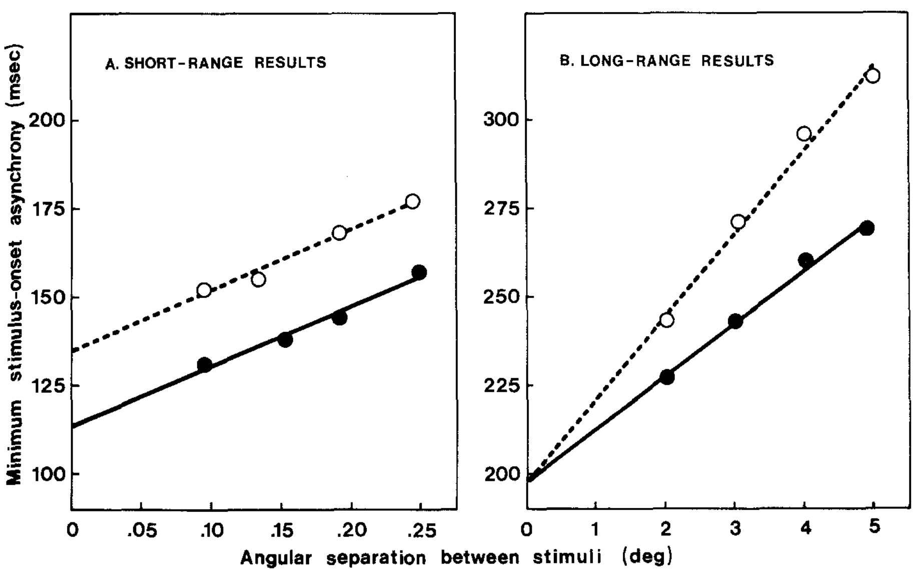

Fig. 2 A and B. Minimum stimulus-onset asynchrony required for perception of apparent movement (averaged across subjects) as a function of the visual angle separating the stimuli, with viewing distance as a parameter (Experiment 2). Viewing distance was 1.5 m (*closed circles* and *solid lines*) or 6 m (*open circles* and *dashed lines*). **(A)** Results for small visual angles fitted by a least-squares pair of parallel lines. Estimated standard errors af the plotted means ranged between 3 ms and 5 ms. **(B)** Results for large angles fitted by a least-squares pair of straight lines with a common zero-intercept. Standard errors ranged between 3 ms and 6 ms.

individual subjects showed significant difference in intercept ($t(8) = 2.54, P < 0.05$), but not in slope ($t(8) = 0.21$, $P > 0.5$), between the short-range functions for the two viewing distances in Experiment 2, and significant difference in slope ($t(8) = 2.37, P < 0.05$), but not in intercept ($t(8) = -.13$, $P > 0.5$), between the long-range functions in Experiment 2.

Discussion

In classical two-stimulus apparent movement displays, competition between alternative paths of movement is minimal. For such displays, the minimum SOA required for beta apparent movement proved to be directly related to the angular stimulus separation over the entire range from 0.1° to 5° sampled in Experiment 1. This result makes an interesting contrast with findings from more complex paradigms, suggesting that the contributions of space and time to processes selecting among competing paths of movement are independent (Burt and Sperling 1981; see also Morgan and Ward 1980).

The main result of Experiment 2 – differential effects of viewing distance on short- and long-range threshold functions – provides strong evidence for the notion (Braddick 1974) that apparent movement can be signalled by each of two processes, a central process that underlies perception of apparent movement over long distances and a more peripheral process that operates over a short range. The long-range results compare with previous data (Attneave and Block 1973; Corbin 1942), suggesting that long-range movement is signalled by a process that operates on the output from prior computations of the positions of the stimuli in physical 3-D space. Our data resemble those of Attneave and Block (1973) by showing effects of both retinal and physical 3-D separation. Note that if the temporal threshold for apparent movement were determined solely by the apparent 3-D separation between stimuli, and the apparent distances equalled the physical ones, the ratio of the slope constants in Experiment 2 (1:1.6) should approximate the ratio of the two viewing distances (1:4). The disparity between these ratios suggests that either the apparent distances in 3-D space differed from the physical ones or else the threshold for long-range movement was determined jointly by the angular and the apparent 3-D separation between stimuli.

For apparent movement over short-range visual angles, the rate of increase in temporal threshold with angular separation of stimuli was independent of viewing distance. This finding would be expected from the assumption that the short-range process, being more peripheral, responds to the retinal separation of stimuli without regard to their apparent depth. The effect of viewing distance on the zero-intercept of the short-range function suggests that the short-range process was facilitated by increase in the retinal size of the stimuli.

Acknowledgement. The authors are indebted to Jørgen Rathje for engineering assistance.

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Received May 24, 1983/May 27, 1983