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TEMPORAL CHARACTERISTICS IN APPARENT MOVEMENT: OMEGA MOVEMENT vs. PHI MOVEMENT

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A vertical line stimulus was presented alternately at two positions on an oscilloscope face, with no interstimulus interval. Observation of this stimulus produced haphazard alternation between a number of movement percepts, which were divided into four categories: phi, omega and partial movement, and no movement. Attention to one category did not increase the proportion of time movement in that category it was reported. Proportion of time reported for each category varied differentially as a function of alternation frequency. Upper and lower displacement amplitude limits were measured as a function of frequency for phi and omega movement. Both limits for omega movement differed from those for phi movement. The results imply that phi and omega movement involve separate processing stages in the visual system.

Introduction

Most studies of apparent movement have used variations on Wertheimer's (1912) original paradigm, which is essentially a single-shot approach to apparent movement. Recently, there has been increasing interest in the use of repetitive stimuli and the study of the response of an observer under steady-state conditions. One type of stimulus that can be used is a continuous alternation of a stimulus light between two positions, corresponding to a repeated classical apparent movement configuration with zero interstimulus interval and intertrial interval. This stimulus may equally be considered as a rectangular-wave displacement in time.

Qualitative results of observation of such a rectangular-wave displacement stimulus have been reported by Saucer (1953, 1954). He found that classical (phi) apparent movement was observed, and under appropriate temporal conditions subjects reported a new type of apparent movement phenomenon, consisting of a "moving shadow" oscillating between the two lights, which he called "omega movement". The repetition frequency at onset of the report of omega movement varied from 3·5–4·5 Hz.

Concurrently and independently, it appears, the omega movement phenomenon was reported by Zeeman and Roelofs (1953). In an extensive study of rectangular-wave displacement of a square with sides subtending 2° 17′, they measured a range of subtly differing percepts which they reduced to six clear-cut descriptions: (1) independent flickering of two separated squares; (2) apparent movement of the black background between two separated squares, which remained continuously visible; (3) apparent movement of the after-images of two squares, i.e. an extension of case 2 where black alternately covered two squares; (4) simultaneous apparent movement of two squares a small distance from their endpoints; (5) apparent tunnel-movement of two squares, i.e. each disappearing in the direction of the other; (6) optimal apparent movement of a single square. Categories 2 and 3 appear to be different strengths of what Saucer calls omega movement. The term "after-image movement" was employed by Zeeman and Roelofs, but it presupposes the mechanism underlying the movement.

The object of the present study was to investigate the conditions of occurrence of omega and phi movement more fully, and, by the use of a rectangular displacement stimulus, to analyze the temporal processing characteristics by means of linear systems analysis. The use of a rectangular displacement stimulus has a number of advantages.

(1) As an apparent movement stimulus it is simpler than Wertheimer's (1912) basic stimulus, since the overall retinal illuminance is time-invariant. The only time-varying feature is retinal position, as the line flips abruptly from one position to the other. The absence of change of retinal illuminance excludes any influence of changes in pupil size.

(2) For a repetitive series of displacements, the principal independent variable is alternation frequency of the stimulus between two positions. Since the line is continuously illuminated, duration in each position varies inversely with frequency. Either proportion of time a given percept is observed, or displacement amplitude for threshold observation, may be used as the dependent variable. It will be seen that a wide range of stimulus conditions and perceptual effects may be studied by thus varying only frequency and amplitude of displacement.

(3) The use of repetitive stimulation makes it possible to study apparent movement phenomena under "steady-state" stimulus conditions. It permits comparison with studies on steady-state effects in rectangular-wave luminance modulation (de Lange, 1957, 1958), and on perception of sinusoidal movement stimuli (Tyler and Torres, 1972).

(4) The discussion section will illustrate the analysis of the visual system, which is possible using logarithmic presentation of criterion responses to steady-state stimuli and other techniques of linear systems analysis. Information may be gained concerning processing characteristics, time and space constants and similar functions of the visual system.

Method

The stimulus used was a bright vertical line on the dark face of a Dumont dual-beam oscilloscope placed on its side, produced by the time base set at a frequency of 30 kHz. It was observed in the dark at a distance of 4 m. The line subtended 2° in height and 2′ in width. Its luminance was 10 ft lamberts and it was viewed with the natural pupil, since stimulus luminance remained constant throughout the experiment. Just below the stimulus lines was a 6 V lamp which the subject was instructed to fixate during observations. The position of the line was controlled by a rectangular-wave signal to the Y-axis of the oscilloscope from a Hewlett-Packard 202A Function Generator, which was continuously variable in frequency from 0·01 to 100 Hz. This apparatus provided a stimulus consisting of a rectangular displacement of a line at variable frequency and with a continuously variable displacement (separation) from 0° to 2° visual angle. The frequency response of the oscilloscope phosphor was 200 Hz ($\pm$ 3 dB).

Experiment I

Perception of rectangular displacement

The rectangular-wave displacement stimulus was viewed by seven naive subjects under a range of rates of alternation and displacement amplitudes. The subjects were asked to describe as accurately as possible how the stimulus appeared to them during a 10-min period. The reports appeared to fall into four clearly defined categories.

Phi movement

This is similar to classical apparent movement of a single perceived line and corresponds to category 6 of Zeeman and Roelofs' study. Subjects reported: single line moving back and forth, line moving predominantly in one direction, line moving past a central position.

Omega movement

Subjects reported: black fog alternately moving to cover each line; black bar oscillating between two light bars, which appears to move more slowly than the flickering of the bars; a dark bar moving across in front of a wider light bar; a dark grating moving steadily past a wide, light bar; two lines with a black cloth rotating in a vertical plane about a central axis, in front of the bars; black vertical rubber shaft oscillating in a circular motion through two light bars; black cloud rotating in a path bowed towards the observer. One monocularly blind subject saw none of these effects and another saw them only after they were described to her.

The omega movement category thus includes both categories 2 and 3 of Zeeman and Roelofs (1953), together with that of a black bar spinning in a vertical plane (usually at higher frequencies) and assorted depth impressions. In spite of the lability and individuality of these descriptions, they may be grouped into a single category. The movement occurs in the opposite direction from phi movement at any given time and involves the opposite contrast (dark area) as the moving object. It should therefore be distinguished from other classical types of apparent movement.

Partial movement

The subjects sometimes had the impression that movement was present in the stimulus, while some parts also appeared stationary or flickering, and reported: a line moving between two fixed lines; a light moving behind two translucent slits; a white snowcloud moving predominately in one direction past two lines; two lines moving alternately towards the centre areas.

Partial movement corresponds to Zeeman and Roelofs' categories 4 and 5. It is probably best considered a transitional category between the other categories described.

No movement

Independent flashing or flickering of two stationary stimuli was observed. Subjects reported two lines flashing on and off alternately; two lines flickering independently at different rates; two bars flickering at indeterminate rates; lights moving up or down within each of two stationary slits.

This category corresponds to the first of Zeeman and Roelofs. The reports of movement within the bright bars have been included in this category since they are not related to either phi or omega movement. They represent the appearance of gamma movement within the lines, as described by Holt-Hanson (1970).

Experiment II

Frequency dependence in the perception of rectangular displacement

In the next three experiments the categories established in Experiment I will be used to examine in depth the parameters of apparent movement in one subject (myself). The first parameter to be investigated was alternation frequency of rectangular displacement. The proportion of time each percept category was reported was measured for a range of frequencies of alternation.

Method

The amplitude of rectangular displacement was fixed at 10′. For each of five frequency settings, the subject was required to press a button while he was seeing percepts corresponding to one of the four categories. The cumulative time during which each category occurred was recorded on a Standard Electric Timer for a 60-s period. The procedure was repeated for each of the four percept categories for five trials. The 20 trials were arranged in random order within each set of categories. The whole procedure was repeated for five settings in random order (3, 2, 5, 7 and 1 Hz). The author served as subject and viewed the stimulus binocularly with normal refractive correction.

The method of measuring the duration of each percept in a separate trial has the disadvantage that during any given 60-s period the subject is set to respond preferentially to a given percept. However, it was found to be difficult to distinguish the perceptual experience into four categories concurrently, with the added difficulty of coding the response while attending to the stimulus. The method of separate recording for each percept described above was therefore adopted. If attending to a given percept increases its duration, then the summed average duration for all four categories should exceed the sampling time of 60 s. For the five alternation frequencies measured (1, 2, 3, 5 and 7 Hz) the sums of average durations were 61, 81, 67, 55, and 58 s respectively. Thus the average summed duration was 64·4 s. The standard deviation of individual sums of durations from this mean was 4·52 s, so that the difference between sampling time (60 s) and average summed duration (64·4 s) was less than one standard deviation. The effect of preferential set was therefore insignificant.

Results

Percentage average durations for which the subject signalled each of the four apparent movement percept categories of Experiment I are shown in Figure 1. The standard deviation of the percept durations on each sampling trial from the mean of the five trials in each frequency condition was computed, and is shown by bars in the figure. Informal observation indicated that below about 1 Hz the subject saw only phi movement, while above about 7 Hz the only percept was of

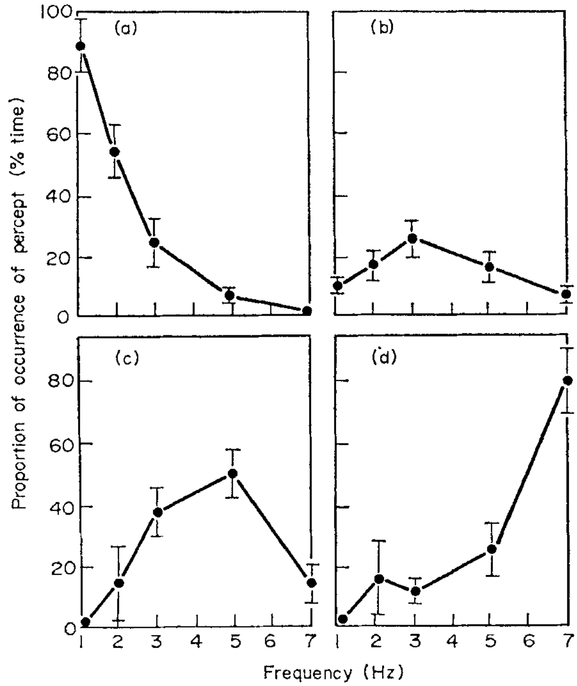

FIGURE 1. Percentage average duration of perception of each of four categories of apparent movement as a function of alternation frequency. Bars indicate standard deviation. (a) Beta movement; (b) partial movement; (c) omega movement; (d) no movement.

two independently flickering lines. Figure 1 indicates that between 1 Hz and 7 Hz, the duration of the perception of phi movement decreased rapidly as alternation frequency was increased. It was replaced mainly by the perception of omega movement, which had maximal durations in the region of 3–5 Hz. There was also some report of partial movement and no movement in this region. By 7 Hz no movement was reported most of the time.

Experiment III

Amplitude limits for the perception of phi movement

The present experiment was designed to investigate the range of amplitudes for which a phi movement perception is reported.

Method

In order to determine maximum and minimum displacements at which phi movement is observable, the lengthy technique of Experiment II was condensed to a modified method of adjustment for each of a range of alternation frequencies. The subject *increased* amplitude of displacement until he no longer observed phi movement for a 20-s period. He then *decreased* displacement amplitude from a higher value until he first observed phi movement. Amplitude of displacement was recorded in each case, and the values for increasing and decreasing thresholds were averaged at each alternation frequency. The author and an emmetropic observer (L.K.T.), who was unaware of the purpose of the experiments, acted as subjects.

A similar procedure was adopted for the measurement of minimum displacement amplitude for phi movement. This procedure corresponds to a determination of the displacement amplitudes for a given ordinate level on the graph of Fig. 1(a). It can only be utilized where the proportion of phi movement is above such a level. Hence the range of frequencies that could be examined was limited in the present experiment by an upper level of 12 Hz. The lower limit was chosen at 1 Hz for comparison with Experiment IV.

Results

Amplitude limits of displacement for phi movement are plotted in Figure 2. Logarithmic co-ordinates are utilized both to show threshold relationships over a 100: 1 range of amplitudes, and because exponential tendencies are more clearly

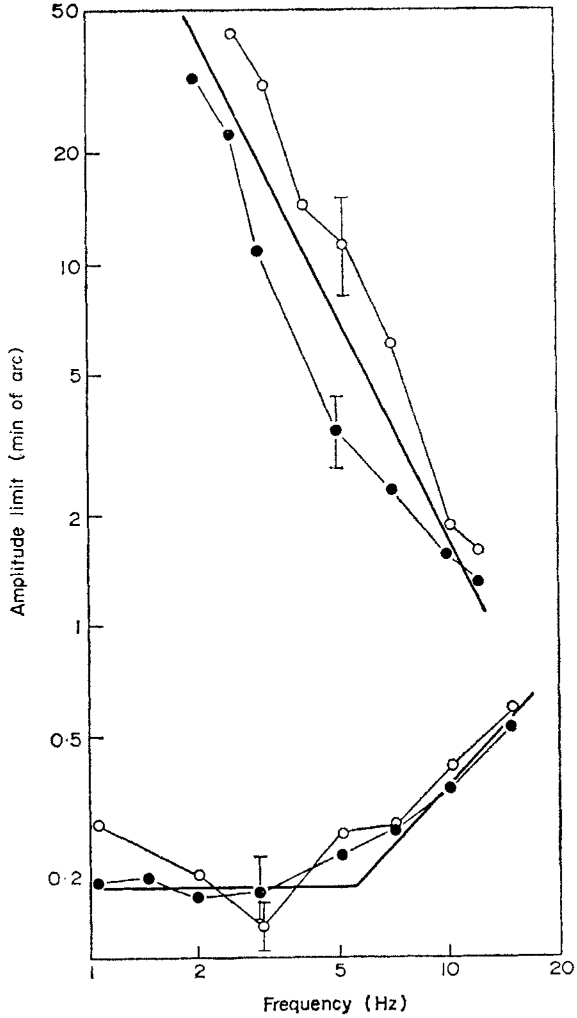

FIGURE 2. Amplitude limits for perception of beta movement as a function of alternation frequency, plotted on log–log co-ordinates. Upper data lines—upper amplitude limit; lower data lines—lower amplitude limit; full circles—subject C.W.T.; open circles—subject L.K.T. Straight lines—asymptotic approximations to curves with slopes being multiples of unit slopes. Note differences in form between upper and lower amplitude limits.

revealed (as straight lines). In Figure 2 the straight lines are fitted by eye to the data of both subjects combined. They have possible slopes of 0, ±1, ±2, ±3 . . ., (see Theoretical Interpretation). The *upper* amplitude limits for the two subjects are close to the straight full line, which has a slope of −2. Some divergence may be due to a variation in movement sensitivity as a function of frequency. The *lower* amplitude limit functions (lower lines in Figure 2) represent the smallest perceivable displacement of the stimulus, and provide a measure of movement sensitivity. It appears that movement sensitivity is approximately constant up to about 5 Hz, when it begins to decrease at a rate approaching a slope of unity.

Discussion

The implications of the slopes shown in Figure 2 will be discussed below, but the fact that the lower and upper amplitude limit functions are so different in form will be considered here. At amplitudes below about 2 min the stimulus bar moves less than its own width, so that further reducing the amplitude of displacement reduces the area of the target that is changing and increases the steady luminance portion at the centre. Above about 2 min, there is no steady component to the stimulus, so that varying displacement amplitude varies the distance between the two flickering stimuli. It is therefore probable that upper and lower amplitude limits are determined by different variables; the proportion of flickering to steady area and the distance separating two flickering lines respectively.

Experiment IV

Amplitude limits for the perception of omega movement

Method

The procedure used for the determination of amplitude limits for the perception of omega movement was a replication of that for phi movement, except that the subject had to report the presence or absence of the moving "black fog" percept of omega movement. The same subjects were tested.

Results

The amplitude limits for the perception of omega movement are shown in Figure 3, which is plotted in a similar manner to Figure 2. It is immediately apparent that the form of the amplitude limits differs markedly from that for phi movement. Over the majority of the frequency region (1·5–6 Hz), the slopes of both the upper amplitude limit (upper lines) and the lower amplitude limit (lower lines) are a good fit to a straight line with a slope of −1 and at high frequencies the upper amplitude limit falls off rapidly, at a rate of the order of −6. The lower amplitude limit falls off with a slope close to −2 at the high frequencies.

Discussion

The shallower slope found for omega than that for phi movement (see Fig. 2) and the shoulder in the omega movement curve, reflect the existence of a region in which omega movement is perceived more readily than phi movement, as was found in Experiment II.

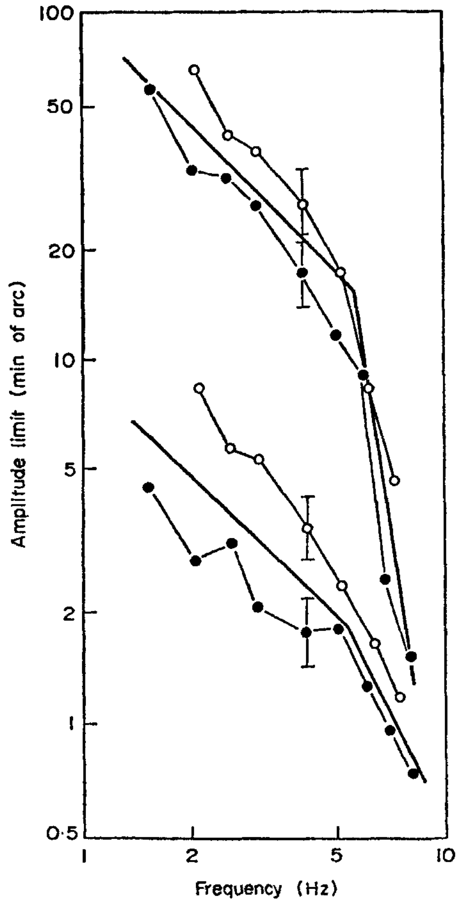

FIGURE 3. Amplitude limits for perception of omega movement. Details as for Fig. 2. Note similarity in form between upper and lower amplitude limits.

It is interesting to find that the lower amplitude limit for omega movement is frequency dependent in a similar manner to the upper amplitude limit (Fig. 3). It appears to have no relationship to the lower amplitude limit for phi movement. The inference may be drawn that the lower amplitude limit for omega movement is not determined by the area of flicker, as was suggested in the case of phi movement. Neither can it be determined by the presence of a fixed amount of dark space between the two stimulus bar positions, as the limit would then be independent of frequency, and would show as a horizontal line on the graph. The lower and upper limits are probably determined by the same factor, since the two are similar in form. A simple model for such a factor is considered below.

Theoretical Interpretation

The difference in temporal conditions for optimal phi and omega movement raises the question as to whether apparent movement can be considered a unitary phenomenon, or whether it subsumes several different processes. A number of authors (Neuhaus, 1930; Kolers, 1963; Graham, 1963) have shown differences between real and apparent movement perception. On the other hand investigators of apparent movement have tended to assume that different *types* of apparent movement involve the same movement processing system. If this were the case, they should have similar temporal characteristics. Although Experiment II shows that omega movement has a greatly different time course from phi movement, this could be explained by a single movement processing system with different inputs for the two types of apparent movement. The input for the perception of phi movement is probably the onset of luminance in each retinal position (Kahneman and Wolman, 1970). Since the contrast and phasing of omega movement are the inverse of those for phi movement, the input for omega movement is probably luminance offset. If signals from luminance onset decayed more slowly than those from luminance offset, the sensitivity for the two types of movement might vary differentially with alternation frequency, as shown in Figure 1. In Figures 2 and 3 the point at which the straight-line approximation to the curve becomes horizontal can be used to indicate the time-constant of the decay. Unfortunately, neither curve shows such a flattening of the curve down to 2 Hz so that data on the decay of the time constant are not available.

It is possible to differentiate between differences in the order (number of stages of integration, interaction, etc.) of two systems and differences in time or space constants. If the system frequency response is plotted logarithmically, then the order of the system determines the slopes of the functions, whereas time and space

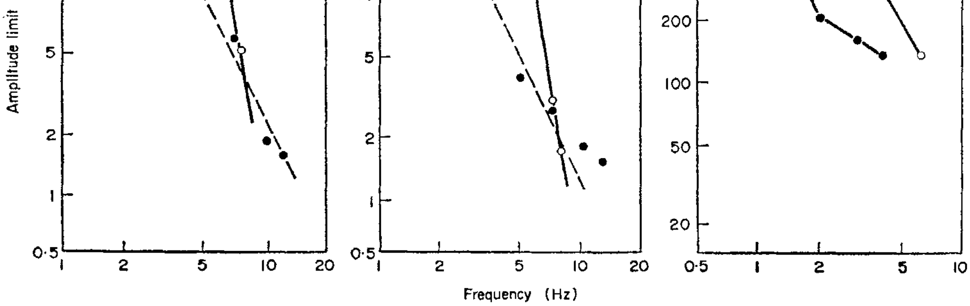

FIGURE 4. Upper amplitude limits for beta movement (open circles) and omega movement (full circles); A and B as replotted from Figs 2 and 3 for subjects L.K.T. and C.W.T.; C as replotted from the investigation of Zeeman and Rofelos (1953). Note differences between the two types of movement which are consistent in the three sets of data.

constants determine their relative displacements. If the system is describable in terms of a discrete number of processing stages, the responses should have slopes of 0, ±1, ±2, . . . etc.

The results of Experiments III and IV are compared in Figure 4 (a) and (b), replotted for clarity from Figures 2 and 3. Below 6 Hz the upper amplitude limit for omega movement (full circles) was inversely proportional to the alternation frequency and to the square of alternation frequency for phi movement (open circles).

Figure 4 (c) shows data replotted from the similar experiment of Zeeman and Roelofs (1953). When logarithmic co-ordinates are used, it becomes clear that Zeeman and Roelofs' data are qualitatively similar to those of the present experiment. Quantitatively the slopes of their functions appear somewhat less than −1 and −2 for omega and phi movement respectively. However, the alternated square stimuli had widths of the same order as their separation. This configuration may well have produced second-order effects which would account for the quantitative discrepancies between the two sets of data, e.g. movement could be seen between either the nearer or further sides of the squares, whichever predominated under each stimulus condition.

The difference in slopes for phi and omega movement implies that phi movement processing is of a different order from omega movement processing, rather than a different input decay time. An example of possible processing characteristics that would lead to this difference may clarify the point. Suppose the omega movement response was produced by offset signals with a simple onset risetime feeding into a zero-order movement processor (in which constant amplitude of input would produce a constant output of a movement signal, regardless of frequency). Conversely the phi movement response might be produced by onset signals, perhaps with a different risetime of onset, feeding into a movement processor which itself had an onset risetime, such that its output for constant input was frequency dependent (i.e. a first order process). These processes would produce slopes of −1 for omega movement and −2 for phi movement. The crucial point is that a difference must occur in the characteristics of the movement processor rather than its inputs, in order to account for the differences in the slopes of the amplitude limits.

A further difference between upper amplitude limits for phi and omega movement occurs above 6 Hz, where the slope for omega movement becomes very steep (of the order of −6), whereas the slope for phi movement is essentially unchanged A slope as steep as −6 probably corresponds to a non-linear process in the omega movement system.

Conclusion

The results show that the perception of apparent movement is not mediated by a unitary process responding to a number of types of simple input from the primary stimulus-encoding stages in the retina. On the contrary, omega movement involves a radically different type of spatio-temporal integration from that for phi movement. Further experimentation will show whether the many other types of apparent movement (as catalogued by Bartley, 1958) fit into one of the same categories and whether further types of processing are revealed in their temporal characteristics.

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