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Objective Measure of the Dynamics of a Visual Movement Illusion

Abstract. *Apparent movement in peripheral vision can be induced by sequential flashing of two dots that are spatially unresolved. Subjects used this illusion to make forced-choice estimates of the directional sequence of the two dots. Performance at this task defines spatiotemporal conditions that induce the illusion without reliance upon subjective distinctions of "movement" from "successivity" and "simultaneity." The dynamics of the illusion, defined in this way, are measured and compared with those for after-flash inhibition and the perception of real movement.*

Two small brief sequential flashes of light in the human peripheral field of vision, separated spatially by a fraction of a degree and temporally by about 50 msec, induce a strong illusion of movement of a "single dot," in the direction of the sequence (*1*). We find that the illusion remains strong, and is still a reliable index of sequential order, even though the dots are so closely spaced (for example, 6 minutes of arc, if presented 22° peripheral to the fovea) that they appear as one dot when flashed simultaneously. This situation, illustrated in the inset of Fig. 1, permits an objective study of the spatiotemporal conditions that induce the illusion; subjects used the direction of the movement illusion to estimate (forced choice) the sequential order of the two unresolved dots. At sufficiently short intervals, subjects reported a single flash with no clear directional properties. At sufficiently long intervals, the illusion also fails and two flashes, spatially superposed, are reported. In both extremes, performance in estimating sequential order falls to chance levels. At intermediate intervals one obtains "band-pass" performance curves, which may define characteristic dynamics of the mechanism underlying the illusion. In contrast with this experiment the usual methods (*2*) of investigating conditions adequate for apparent movement rely upon subjective reports of "simultaneity," "good movement," and "successivity" by highly trained subjects viewing sequential flashes of two spatially distinct lights.

As illustrated in Fig. 1, a digital computer (Digital Equipment Corp. PDP-8) randomized (*3*) a list of 24 different two-flash stimuli with respect to right-left order and time interval between flashes. In response to the subject's pushing a button signifying "ready," the computer counted out a 1-second wait, rang its typewriter bell (ready-fixate signal), and after another 1-second wait presented the appropriate pair of flashes 22° peripheral to the fixation point. Subjects, viewing the stimulus monocularly and with heads in a chin rest, responded by pushing one of two buttons signifying "toward the right" or "toward the left." After presenting all 24 trials of one subset, the computer rerandomized the list and awaited the next "ready" command. After a suitable number of trials, the computer printed a summary of performance versus time interval. Data from several such experiments are shown in Fig. 2. Naive subjects produced similar curves, after a few minutes of practice with "easy" (50-msec) time intervals, in sessions of about 240 responses to the computer. Inclusion of "blank" (nearly simultaneous) presentations yielded no significant directional bias at the dot luminances used in the experiment of Fig. 2. Performance as in Fig. 2 is relatively insensitive to luminance level of the dots and the surround, and to the position or orienta-

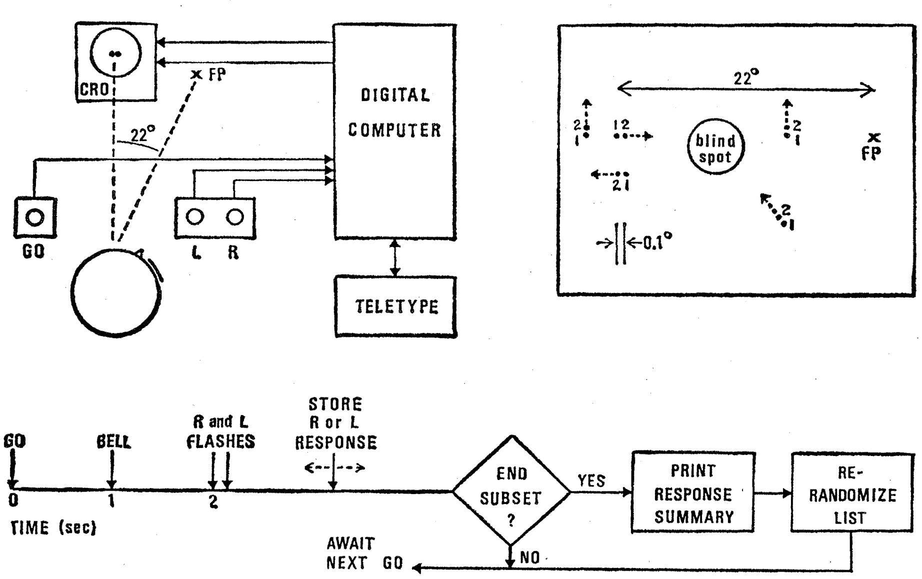

Fig. 1. Block diagram of the forced-choice experiment described in the text. The general arrangement of subject, oscilloscope, fixation point (*FP*), and computer are shown at the upper left. At the bottom of the figure, the sequence of events associated with one stimulus presentation is summarized. Inset: the visual field of the left eye, schematizing the subjective "fine-grain" movement illusions generated by the flashing of two dots separated by 0.1° in various retinal positions, spatial orientations, and sequential orders (first dot labeled "1"; second dot labeled "2," flashed 50 msec later). The dashed arrows suggest the illusory movement as described by most observers.

tion chosen for the sequential stimuli. Similar performance was obtained with the use of fiber optics to produce the dots in a black surround.

In dichoptic viewing of the two dots, illusions similar to the monocular illusions can occasionally be obtained. On the other hand, by careful positioning of the two sequential flashes near the mutual boundary of the two hemiretinae of one eye (the two stimuli were presented several degrees below the fixation point), which may amount to "dichogeniculate" presentation, all three subjects tested found a small range of positions in which the illusion was abolished.

Involuntary eye movement appears not to be a factor in these experiments. Both the illusion and performance curves similar to those of Fig. 2 were readily obtained in stabilized vision (*4*). Monitoring of eye position (*4*) (± 1 minute of arc) during performance showed that subjects were successful

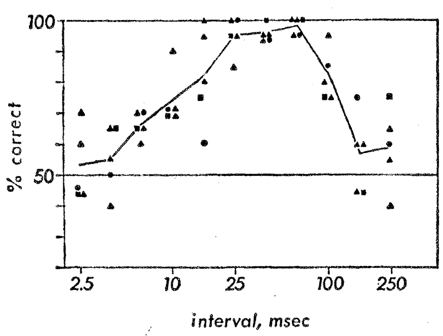

Fig. 2. Performance at guessing which of two spatially unresolved dots was presented first versus temporal separation (logarithmic interval scale) of the dot presentations. The guesses were based on the direction of a movement illusion. Two 3-minute-of-arc-diameter dots on a fast-phosphor oscilloscope, separated spatially by 7 minutes of arc, were presented monocularly for 1 msec each to the left eye, 22° to the left of a fixation point. The pair of dots (luminance 0.3 lambert) was centered in a 7°-diameter surround (luminance approximately 10^{-5} lambert), the remainder of the visual field being occupied by a black felt screen. Each point represents the percentage of correct responses in 20 computer-controlled trials (10 right-first and 10 left-first) at a particular time interval. The symbols denote three separate experiments for one subject (triangles) and one experiment for each of two other subjects (squares and circles). The solid line connects averages for the five experiments. The scatter of points at the smallest and largest intervals is about that expected for *n* successes in 20 independent trials with probability of success near .5.

in suppressing microsaccades during the approximate 1-second temporal neighborhood of the two flashes.

We have not been able to rule out the view that the above "fine-grain" movement illusion results from stimulation of the neural mechanism underlying the response to real movement. In fact, the characteristic cutoff near 100 msec in Fig. 2 is compatible with the usual range of velocity thresholds for perception of real movement (*2*), if it is assumed that correlated sequential stimulation of retinal locations separated by about 2 minutes of arc limits movement perception in this part of the periphery. The fact that the range of perceived real velocities (*5*) is greater than that of the temporal bandwidth in Fig. 2 follows naturally if there is a range of such contributory retinal spacings (greater than 2 minutes of arc).

Optimal interflash time intervals for the above illusion are similar to those for the phenomenon of metacontrast (*6, 7*), which is also stronger in peripheral vision than in foveal view (*7*) and difficult to induce unless the two stimuli are more closely spaced than about a degree (*7*). For metacontrast, Alpern (*8*) and Alpern and Rushton (*9*) concluded that the rod mechanism and Stiles' three cone mechanisms do not have cross interactions (each speaks only to its homonymous neighbors). The hypothesis that the two-flash illusion shares this property, as well, suggests a novel experiment. After a rod bleach, the sequence "blue-blue" should on this view induce the fine-grain illusion whereas "blue-red" should not.

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3. The 24 stimuli comprised one left-then-right and one right-then-left sequence at each of 11 time intervals logarithmically spaced in the range of 2.5 to 250 msec, and two nearly simultaneous or "blank" stimuli. The randomized ordering was done by successive sampling from the uniform distribution over these stimuli, without replacement, until all 24 had been selected. Subjects reported that they were unable consciously to take advantage of the lack of replacement (basing guesses of direction on the "unused" stimuli toward the end of each 24-tuple), since such a small fraction of the 24 responses were based on certainty of the direction (see Fig. 2).
4. These controls, done with D. Fender and P. Nye, employed full-eye contact lenses. A stalk on the lens carried a mirror or light source for stabilized vision (at least 97 percent stabilization, with typical image-fading, was achieved in these experiments) or photomultiplier measurement of eye position, respectively. The optical system is nearly identical to that described by M. B. Clowes and R. W. Ditchburn [*Opt. Acta* **6**, 252 (1959)].
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Water on the Moon

O'Keefe (*1*) has given me much negative credit for a suggestion due to Gold as stated in my brief note in regard to where the sediment of the crooked rills of the moon was deposited (*2*). This note also mentioned the possibility of sediment at the end of the rill flowing out of a break in the western wall of Krieger. The sediment apparently has covered a rill flowing north from the region of Aristarchus. This may indicate a solution to the sediment problem. Probably, if the flow had continued, it would have flowed over or around this sediment, deepened the first part of the rill and left a shallow rill through or around the sediment, and this may be the mechanism applicable to the longer rills. All right, attack if you wish to. This is, so far as I recall, my suggestion, not that of my good friend, T. Gold. Possibly Lingenfelder *et al.* (*3*) considered some modification of this idea. I am not at all convinced that Gold's mechanism may not contribute to the problem to some extent.

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