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INTERACTIONS BETWEEN MOTION AFTEREFFECTS AND INDUCED MOVEMENT

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Abstract—Two illusions of visual movement—induced movement, and the aftereffect of movement—can interact. Induced apparent movement of stationary areas can produce an aftereffect, and conversely, an aftereffect of real movement can induce apparent movement into stationary neighboring areas.

The real movement of images across the retina can produce two distinct illusions of movement. First, a small stationary spot or area will seem to drift to the left if it has a large surround which moves slowly to the right. This is *induced movement*, which has sometimes been called simultaneous motion contrast (Duncker, 1929; Brosgole, 1968; Over and Lovegrove, 1973; Tynan and Sekuler, 1975). Secondly, following prolonged fixation of a pattern which moves to the right, a stationary pattern will appear to drift to the left. This is the *aftereffect of movement*, which has sometimes been called successive motion contrast.

Usually, real movement of a surround is necessary to create induced movement. However, we have found that an aftereffect of movement in a large surround suffices to induce movement into a small stationary area. Also, movement of images across the retina is usually necessary to generate the aftereffect of movement, and the effect is confined to the retinal area stimulated by the moving pattern (Anstis and Gregory, 1965). However, we have produced aftereffects from apparent or induced movement.

Our subjects stood inside a large vertical cylinder made of tracing paper. A random dot pattern was back projected on to the cylinder; this pattern rotated at 1 rpm around the subject's line of sight, somewhat like a large, vertical rotating disc. The display filled virtually the entire field of view, except for two stationary, concentric annuli which were centered at eye level on his fixation point and which were filled with stationary texture from a second projector. The annuli had radii of 26° and 45° and were 1° wide. When the background was rotated counterclockwise, strong induced movement was reported on the stationary annuli, which appeared to rotate steadily clockwise. In fact, the movement of the background itself was often barely noticed by the subjects who often thought that the annuli alone were moving, or felt that their own bodies were swaying, leaning over, or counterrotating [see Held, Dichgans and Bauer (1975) for a study of this phenomenon].

EXPERIMENT 1

Subjects viewed this display for 1 min, and the rotating background was then stopped: it showed only a feeble movement aftereffect (Wohlgemuth, 1911), but the annuli showed a counterclockwise aftereffect lasting 27.3 ± 5.7 sec (mean and S.E. of seven subjects $\times$ four trials) even though they were stationary throughout the experiment. Torsional eye movements are excluded as a possible factor in these aftereffects, by means of controls built into experiments 2 and 3 described below.

We postulate two components in this induced movement aftereffect: a "type A" aftereffect, such that the induced movement of the (stationary) adapting annuli built up an aftereffect during adaptation which was elicited during the test period; and also a "type B" aftereffect, such that the movement aftereffect of the background was spatially inducing a secondary aftereffect into the annuli during the test period itself.

Two further experiments were performed to separate out A and B effects. In experiment 2, the background was made to move in opposite directions during successive time intervals, in order to abolish any temporal buildup of aftereffects in the background. In experiment 3, adjacent spatial areas of the background were made to move in opposite directions, in order to abolish any spatial induction of apparent movement into the annulus.

EXPERIMENT 2

To produce a type A effect only [induced movement producing an aftereffect: Fig. 1 (ii)], the adapting background was made to rotate alternately clockwise and counterclockwise for 2.5 sec in each direction for a total adapting time of 3 min. During the clockwise phases, the outer annulus was blacked out and appeared stationary, while the inner (physically stationary) annulus was textured and appeared to rotate counterclockwise. During the counterclockwise phases, the inner annulus was blacked out and the outer annulus appeared to rotate clockwise. So by pairing the illumination of the annuli with suitable rotations of the background, the outer annulus appeared alternately stationary and rotating clockwise, whilst the inner annulus appeared alternately stationary and rotating counterclockwise.

After 3 min of adaptation, the rotation of the background was stopped. It showed no aftereffect, since it had been rotating equally in two opposite directions, so it could not induce any type B effects into

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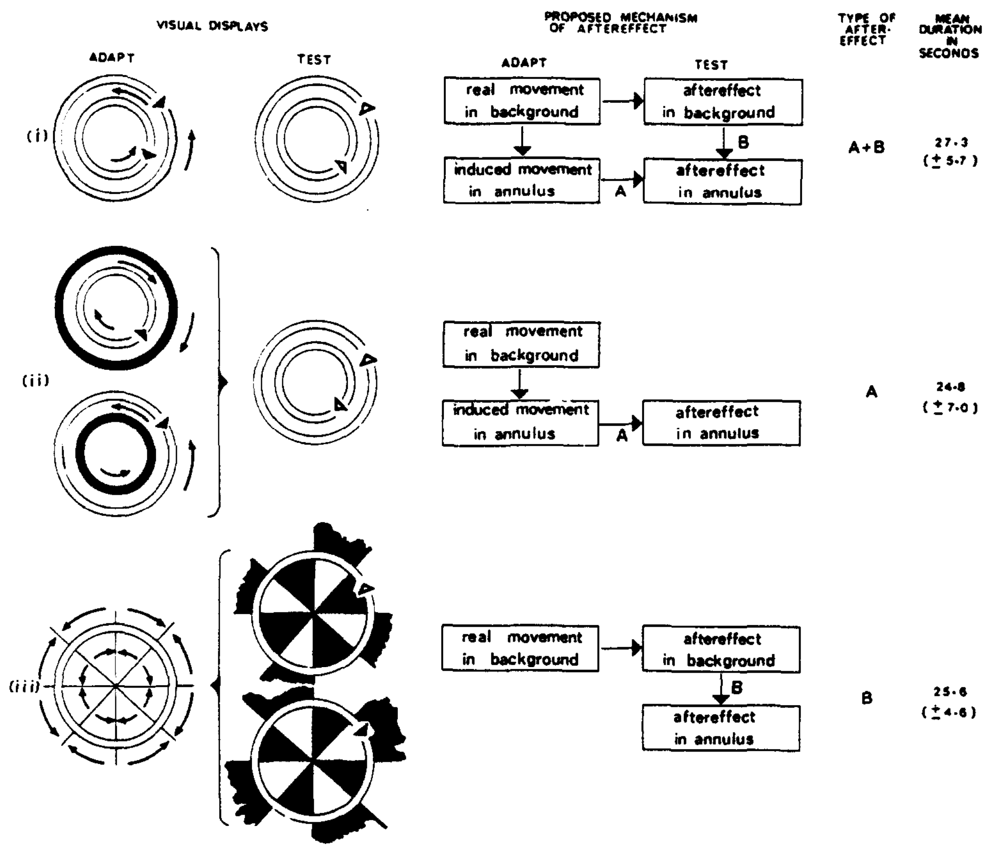

Fig. 1. (i) Top row left columns: counterclockwise rotation (←) of adapting background induced apparent movement (◀) into stationary annuli. When background was stopped, stationary test annuli showed counterclockwise aftereffect (◁). Middle columns: Two possible mechanisms might be at work: A, induced movement of adapting annuli might build up aftereffect, or B, surround movement might build up aftereffect in surround, which would then induce aftereffect into annuli during test period. (ii) Middle row left columns: adapting background first moved counterclockwise, inducing clockwise motion into outer annulus while inner annulus was blacked out. Then background moved clockwise, inducing counterclockwise apparent movement into inner annulus while outer annulus was blacked out. Direction of background movement was reversed every 2.5 sec, for a total adapting time of 3 min. Middle column: since background had moved equally both ways, it showed no aftereffect. Aftereffect in annuli was type A lasting 24.8 sec. (iii) Bottom row left columns: adapting background was divided into sectors, half moving clockwise, half counterclockwise. Adapting annulus looked stationary, and was. Background was then stopped and half its sectors blacked out: remaining sectors showed aftereffect and (middle column) induced type B aftereffect into the stationary test annuli.

the test annuli. But the outer annulus showed a counterclockwise aftereffect and the inner annulus showed a clockwise aftereffect. These lasted 24.8 ± 7.0 sec and must have been of type A.

EXPERIMENT 3

To produce a type B effect only [an aftereffect producing induced movement: Fig. 1 (iii)], sectored masks (and an additional motorized projector) were used to divide the adapting background up into 16 sectors, somewhat like a dartboard, such that the textures in alternate sectors rotated in opposite directions. The sectors themselves could be regarded as stationary "windows" whose boundaries were stationary, but through which texture could be seen to move past (so the display looked something like a large field of moving texture viewed through a mirror kaleidoscope). There was only one annulus (radius 45°), which was stationary, textured and not sectored. The sectors were divided up so that each part of the annulus had its inner edge abutting clockwise motion and its outer edge abutting counterclockwise motion, or vice versa. Thus, the display produced no movement in the annulus.

After 1 min of adaptation, the rotating background sectors were stopped, and every alternate sector (1, 3, 5, ...) was blacked out. The remaining sectors (2, 4, 6, ...) which had been rotating clockwise were filled with stationary texture. They showed a short, feeble aftereffect in a counterclockwise direction but the stationary test annulus appeared to rotate strongly clockwise for 25.6 ± 4.6 sec. When this aftereffect had stopped, sectors 1, 3, 5 were blacked out, and sectors 2, 4, 6, ... which had rotated counterclockwise were now filled with stationary texture. These showed a feeble clockwise aftereffect; and the annulus now appeared to rotate counterclockwise with an aftereffect which lasted for a further 21 sec. It is known that an aftereffect can be stored for a while by blacking out the texture on which it is perceived (Spigel, 1960, 1962, 1964; Honig, 1967), so our results show that the direction of the movement aftereffect on the annulus was dependent on the direction of the aftereffect on the illuminated background areas—a type B effect.

Duncker (1929) noticed that slow real movement of a large surround was often barely visible to his subjects, but led to pronounced induced movement of a small target. In the same way, the motion aftereffects in our backgrounds were themselves barely visible to our subjects, but led to pronounced apparent aftereffects in the annulus.

In conclusion, both A and B aftereffects can be elicited independently, so (A) induced movement can cause an aftereffect, and conversely (B) an aftereffect can cause induced movement. Conventional aftereffects caused by real movement are usually attributed to the adaptation of visual neurons which are selectively sensitive to movement (Barlow and Hill, 1963). However, there is some evidence that simple motion on its own may not suffice to generate an aftereffect unless there is also shearing or relative motion in the visual field. We found very little aftereffect in experiment 1 after viewing a rotation of the whole visual field around the line of sight; and Anstis (1961) and Day and Strelow (1971) reported that a field of moving (translating) stripes seen through a window showed little aftereffect unless this window had a stationary patterned surround.

Hence we surmise that the new aftereffects reported here are due to the adaptation of visual neurons which respond to *relative*, not absolute motion, such as those reported recently in the cat and monkey (Bridgeman, 1972; Burns, Gassanov and Webb, 1972; Mandl, 1974). Such units, we speculate, might receive mutually inhibitory inputs from lower-order motion detectors, which themselves respond to movements in the same directions but in adjacent retinal areas. Some psychophysical support for this can be found in Tynan and Sekuler's study of induced movement (1975), in which they used a center and surround of spatially random dots, and measured the effect of surround velocity on the center's perceived velocity. They concluded that "mechanisms responding to the center motion were inhibited by units responding to the surround" (p. 1236). Holmgren (1974) also found that the perceived velocity of a part of a moving random dot pattern was dependent on the velocity in adjoining areas. A computer was used to generate various distributions of velocity in arrays of moving random dots, and his subjects estimated the velocity of many moving points along these distributions. The perceived velocity at any point could be predicted from the same rules that Mach (1866) had used to predict the perceived brightness of points along a luminance distribution. Walker and Powell (1974) and Loomis and Nakayama (1973) have reported similar phenomena.

Thus, lateral inhibition between motion detectors could lead to a mechanism which responded to differences in velocity between adjacent retinal regions. However, such a mechanism would not on its own explain why movement is perceived more in our annulus than in the background, whenever one moves relative to the other. Perhaps motion is always attributed to the smallest visible object, or perhaps the mean velocity of the whole visual field is computed and neurally subtracted from each part of the field (Burt, in press).

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