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RESEARCH NOTE

ACUITY FOR APPARENT VERNIER OFFSET

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Abstract—Observers viewed an apparently moving vertical bar, displayed sequentially at a series of discrete positions on an oscilloscope face. When the plotting sequence was such that the upper half of the bar was always displayed slightly before the lower, the bar appeared to be broken and offset at the middle, with the upper segment leading the lower (although they are actually displayed at identical horizontal positions). Acuity for detecting this illusionary offset is very fine indeed, almost as fine as that for detecting real offsets. It is further shown that such an offset can be detected only if the bars are seen to be in motion.

INTRODUCTION

When a moving target is viewed under stroboscopic lighting, so that it is illuminated only at discrete stations, the target appears to move past the stations and across the spaces between them. The phenomenon is readily observable with cine films, which display a sequence of stationary pictures at a rate of 18 or 24 Hz, and with television. Recent studies (Ross and Hogben, 1975; Morgan, 1975; Burr and Ross, 1978) have firmly established that not only do stroboscopically illuminated targets appear to move smoothly from one stop to the next, but also, in between illumination, they are seen to occupy positions between those where they are actually exposed. This means that, within limits, we see stroboscopic motion as identical to real motion. Here I investigate this matter further, examining the circumstances under which it occurs, and measuring acuity.

METHOD AND GENERAL OBSERVATIONS

The stimulus was a thin vertical bar, made up of two segments, each intensified for 50 μsec at 25 msec intervals at seven successive stations, horizontally separated by 2.5′ or arc. When the segments were synchronized, the impression was of a single horizontal bar moving smoothly across the field of view. The direction in which the train of bars proceeded was randomized between trials, the display commencing 15′ either to the left or the right of the fixation point, and terminating at the fixation point. Brief displays of 150 msec, with randomized direction of motion, were used to ensure that there was insufficient time for the observer to commence tracking the target.[1] The bars were generated on a point plotting Textronix 602 oscilloscope (equipped with fast-fade P15 phosphor) under control of PDP 8/I or 8/E digital computer. Each of the two segments making up the bar was 1° high, 5″ wide, intensified to a contrast 100 times detection threshold, against a uniform background of 5 cd.m^{-2} mean luminance. Each segment was under independent control and could therefore be displayed at different times, or in different horizontal positions.

For the initial observations the two segments were displayed at the same sequence of stations, but at different times, with the upper always leading the lower segment by 10 msec. On viewing this display, observers saw a distinct vernier offset in the bar (see Fig. 1). Although the two segments were imaged to the same horizontal sequence of retinal locations, the upper segment seemed displaced from the lower, always leading as the bar moved towards the fixation

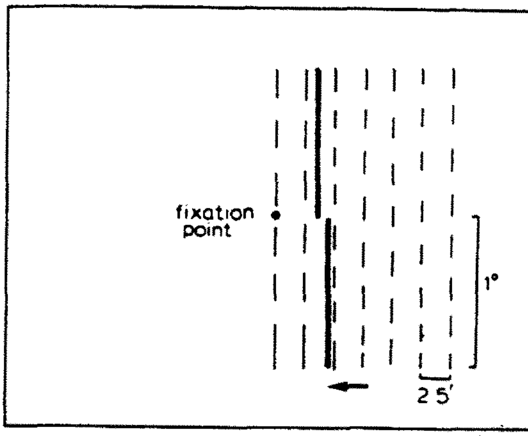

Fig. 1. Appearance of stimulus when the upper segment is displayed 10 msec before the lower (not to scale). The seven locations where the bars are actually illuminated are represented by dashed lines. The plotting sequence is best conceptualised by considering these locations to be transparent slits in an otherwise opaque screen, behind which a pair of offset segments is passed. The upper segment will arrive at each slit a short time before the lower.

[1] The latency for pursuit eye movements under these conditions was about 150 msec, in good agreement with measurements made by Westheimer (1954).

point. The visual system failed to report accurately the series of colinear bars imaged on the retina, but rather responded to the whole sequence as if it represented a vernier offset bar in real motion, where a temporal offset would always correspond to a spatial offset.

ACUITY

The first experiment measured acuity for detecting vernier offsets produced in the way just described, and for real offsets, in order to compare the two under similar conditions. A forced choice paradigm was used in which observers were required to identify the direction of the apparent offset of top to bottom segment. Trials were selected from two sets of conditions, and presented at random. In one condition the segment pairs were displayed at the same position with varying temporal offsets, and in the other they were displayed at the same time with varying spatial offsets. Both conditions can be considered to be stroboscopic samples of the same event: a pair of line segments moving at $1.6° \sec^{-1}$. They are strobed either at a fixed rate, producing spatially offset retinal images, or at fixed locations producing a temporal offset whose magnitude and direction is equal to the spatial offset divided by the target velocity. Thus spatial acuity can be calculated and compared for the two conditions.

Responses (200 for each condition) were collected from two observers, DB and DR, one in Cambridge and one in Perth, and the acuity threshold determined by probit analysis of the frequency of correct identification (Finney, 1952). Using the criterion of 75% correct identification, acuity for spatial offset was found to be 6.6 and 10.3" for DB and DR respectively, and acuity for temporal offset was 11.0 and 12.8" (see Fig. 2). Spatial acuity is evidently finer than temporal acuity. Nevertheless, acuity for the temporal condition is surprisingly good, considering that the retinal image carries no spatial information about the offset. It is also interesting that the temporal delays corresponding to the minimum detectable apparent offset are as short as 1.9 and 2.2 msec, very similar to Westheimer and McKee's (1977) measurements of the minimal delay for adjacent stimuli to produce detectable apparent motion.

DEPENDENCE ON THE PERCEPTION OF MOTION

The second experiment was designed to examine whether the sensation of apparent motion is necessary for temporal offsets to be seen as spatial offsets. Acuity was again measured, under two different conditions: one which produced a strong impression of motion and one which did not. This experiment was like the previous one, except that only the last two bars carried any displacement information. The segment pairs of the first five bars were displayed simultaneously at the same position, while the last two were offset in space or in time as before. 100 responses were collected for each condition, yielding spatial acuity thresholds of 15" and 13" (for DB and DR respectively) and temporal thresholds of 20" and 19".

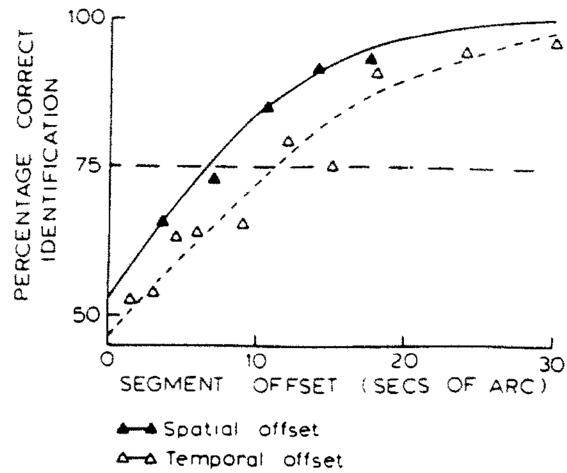

Fig. 2. Percentage of correct identification of spatial and temporal vernier offset for subject DB. 75% accuracy is attained for spatial offsets of 6.6" and temporal offsets producing an apparent displacement of 10.3". This corresponds to a delay of 1.9 msec.

While both these thresholds are higher than those of the previous experiment, they remain comparable.

The experiment was then repeated without the first "lead up" bars, so that only the last two containing the offset information were displayed. With only two bars in the sequence there is a weak illusion of motion, but this is far less compelling than when all seven stations are illuminated. While spatial acuity was virtually unaffected by this procedure, temporal offsets became completely undetectable. The spatial acuity thresholds were 20" and 13", whereas even the largest delay of 10 msec lead to only 67% correct detection in the best case (see Fig. 3). Removing the lead up bars, which in themselves contained no offset information, prevented the observer from detecting temporal offsets. Evidently temporal offsets can be detected only when the target is seen to be in smooth motion.

The experiments reported here reveal the fine sensitivity of the visual system in detecting vernier misalignment from severely limited information. The trajectories of an offset pair of line segments were sampled and displayed stroboscopically in a manner which deprived observers from any spatial information about their offset. Vernier misalignment could still be detected solely on the basis of temporal information, with almost the same precision as with free access to spatial information. The problem remaining is to discover the mechanisms of vision responsible for preserving vernier information under these conditions.

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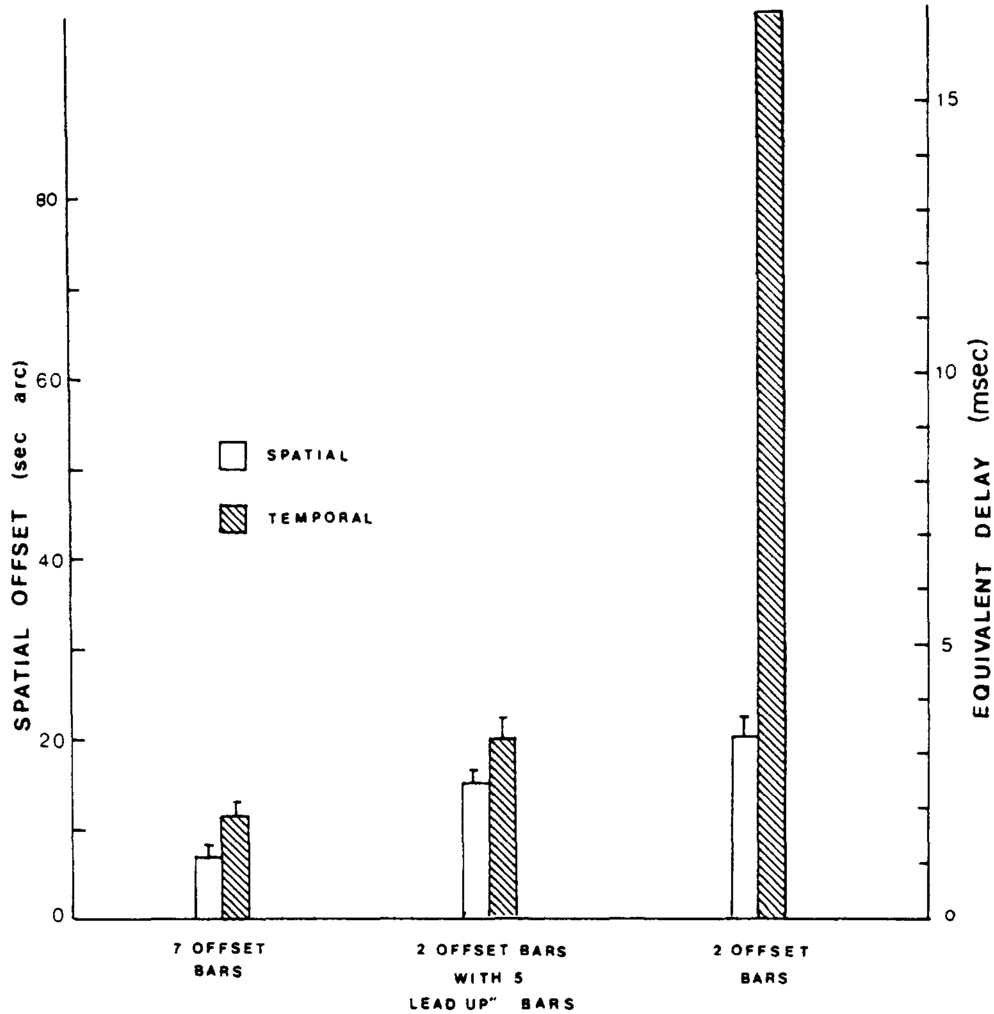

Fig. 3. Comparison of temporal and spatial acuity for DB under three conditions (see text for details). When seven bars were displayed in sequence, producing strong apparent motion, the temporal and spatial thresholds were comparable. With only two bars, temporal offsets were almost impossible to detect.

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