Binocular stereopsis without spatial disparity*

DAVID N. LEE†

Cornell University, Ithaca, New York 14850

Binocular stereopsis has traditionally been studied mainly under static viewing conditions. There has consequently been the tendency to view binocular stereopsis only in terms of the pickup of purely spatial (time-frozen) disparity. However, whenever there is movement of objects or the O, the structure of the light entering each eye undergoes continuous change, and so a different type of disparity—kinetic disparity—is made potentially available to the binocular system. That kinetic disparity can, in fact, be picked up is shown by the present experiment, in which there was no spatial disparity information available about the three-dimensional motion path of an object; only kinetic disparity information was available. This suggests that a clear distinction should be made between binocular-static and binocular-kinetic space perception.

How the visual system picks up information about the layout of the environment, about the movement of objects in it, and about the movement of the O himself is a problem central to the psychology of perception. The information is potentially available in the structure of the light entering the eye, i.e., in the structure of the optic array (Gibson, 1966). In particular, with binocular vision there are two optic arrays, and because the eyes are at different positions, the two optic array structures are always slightly disparate. The binocular disparity relation between the two optic array structures is, itself, potential information for perception.

The capability of the human visual system for picking up binocular disparity information has been much studied, but mainly only under *stationary* viewing conditions. Under such conditions the two optic arrays are time-frozen, *purely spatial* structures. There has consequently been the tendency to consider binocular stereopsis in terms only of the pickup of *purely spatial* disparity.

It is questionable whether this view of binocular stereopsis is adequate for a general theory of binocular space perception. In particular, it may be argued that it is inadequate for a theory of binocular-*kinetic* space perception. For when an object moves in the world, or when the O moves, the structure of the optic array at each eye undergoes continuous change. That is, the optic array structures are spatiotemporal, not purely spatial. To explain the perception of the motion of an object in three-dimensional

space in terms of the pickup of purely spatial binocular disparity, therefore, raises difficulties. It may, of course, be argued—and this view seems to be widely accepted, at least implicitly—that the binocular system essentially treats each continuously changing optic array structure as a sequence of purely spatial time-frozen structures rather like the frames of a stereo motion-picture film, and then picks up purely spatial disparity at each successive moment in time. But is this an appropriate way of looking at the problem? Instead of conceptualizing the instantaneous structure of a continuously changing optic array as a purely spatial structure, it may be conceptualized in a broader way as a spatiotemporal structure or flow field (Gibson, 1966), which is the type of concept found useful, for example, in dealing with problems of fluid flow. This latter concept has the important advantage that not only are the purely spatial properties of the optic array structure taken into account but also the time-dependent properties, such as the velocities, and rates of occlusion and disocclusion of optical elements in the array.

Let us refer to the set of purely spatial properties of the instantaneous spatiotemporal structure of an optic array simply as the *spatial structure*, and the set of time-dependent properties as the *kinetic structure*. These concepts then make it possible to talk about the relation between two instantaneous spatiotemporal optic array structures at two different levels. It may be, for example, that, at an instant in time, the spatial structures of two optic arrays are identical, but the kinetic structures are different; alternatively, the two kinetic structures may be similar, but the spatial structures quite different. As an example of the former, consider the two optic arrays corresponding to the same textured surface moving up and moving down behind a window. Clearly, the two

kinetic structures are always different, but at certain instants the spatial structures will be identical. As an example of the latter, consider the same window with either of two differently textured surfaces moving down behind it. The spatial structures of the corresponding optic arrays will then always be quite different, but the kinetic structures will be similar.

By applying these concepts of spatial structure vs kinetic structure to the problem of binocular-kinetic space perception, we may then formulate two types of binocular disparity: *kinetic disparity*, as the relation between the two kinetic optic array structures; and *spatial disparity*, as the relation between the two spatial optic array structures. While it may be said that, in binocular-kinetic space perception, kinetic disparity information is always *potentially* available, it remains an open empirical question whether that information can, in fact, be picked up. The following experiment was designed to answer that question.

A moving object display was designed such that information about the three-dimensional motion path of the object was potentially available only through binocular disparity and, furthermore, only through *kinetic* disparity, not through spatial disparity. If the motion path of the object could be perceived under such restricted conditions, this would show that the binocular system is capable of picking up kinetic disparity as such.

A stereoscopic pair of motion-picture films was used. These films were generated on a computer. However, their construction can perhaps be more clearly described by a physical analogy. Imagine a vertical opaque white rectangular card with a thin black border, randomly textured with black dots. Take a thin rectangular strip of similarly textured material and lay it vertically on the card so that its ends are coincident with opposite inner edges of the border of the card. Now move the strip horizontally in discrete steps, such that its overall motion is simple harmonic (pendulum-like) oscillation about the center of the background. If at each step the display were filmed frame by frame, and care was taken that the strip was completely undifferentiable from the background in each film frame, then a film formally equivalent to one of the experimental films would have been produced.

In each film of the stereoscopic pair, black dots randomly covered approximately 15% of the white area of both the background and the strip; the width of the strip was 10% of the background width; and a complete

*This research was supported by the Office of Naval Research under Contract Nonr-1866(52) with Harvard University. A paper based on the research was presented at the meetings of the Eastern Psychological Association, April 1970. The computer films were made at the M.I.T. Lincoln Laboratory, and the author is grateful to R. N. Davies and I. Goldstein for their help in producing the films.

†Present address: Department of Psychology, University of Edinburgh, Edinburgh, Scotland.

Fig. 1. A stereoscopic pair of frames taken from the experimental films. No strip is visible in either frame alone or when the two are viewed stereoscopically, since the texture patterns are different.

oscillation of the strip, across an 80% central area of the background, occupied 72 frames. However, the actual texture patterns of the two films were quite different (see Fig. 1).

Two electronically synchronized projectors were used in conjunction with a beam-splitter mirror to superimpose the images of the two films on a rear-projection screen. The films were made into 72-frame loops so that they could be run continuously at 10 fps. By means of appropriate crossed-polarized filters placed in front of the projector lenses and the O's eyes, one film was rendered visible only to the right eye, the other only to the left eye. Twelve Os with normal binocular stereopsis served in the experiment, and their observations were clear and unanimous.

Let us first consider monocular viewing of either film alone. In that case, the strip is not—and indeed cannot be, because of the nature of the film—differentiable from the background when it is stationary, i.e., when the projector is stopped on any one film frame (see Fig. 1). However, when the projector is running, a strip with well-defined edges is clearly seen to be oscillating from side to side in front of the background. The kinetic information, in the moving case, is provided by the deletion and accretion of background texture as the leading and trailing edge of the strip move across it (Kaplan, 1969). The strip is seen at an indeterminate distance in front of the background, there being no more specific information available.

Now let us consider the stereoscopic viewing of the films. Since the texture patterns of the two films are quite different [e.g., they are not correlated stereo patterns of the type developed by Julesz (1964)], when any stopped pair of frames is viewed stereoscopically no strip can be seen, only random texture. The

reader may see this for himself by viewing Fig. 1 as a stereogram. It follows therefore—and this is an essential factor in the design of the experiment—that when the projectors are running there is no spatial binocular-disparity information available at any instant that specifies even the existence of the strip.

The kinetic structure of the optic array at each eye was therefore the sole source of information specifying the existence of the strip. To test whether or not the disparity relation between the two kinetic structures could be picked up, thus affording information about the motion path of the strip, one film was put a frame or two in advance of the other. This meant that the kinetically defined moving strip visible to one eye was always slightly ahead of that to the other eye. Thus kinetic disparity was introduced between the binocular optic arrays which, if it were picked up, should provide information for the motion of the vertical strip in depth around a horizontal

elliptical path. Further, the direction of motion should be counterclockwise or clockwise according to whether the left-eye or the right-eye film was ahead (see Fig. 2). These predictions were confirmed by all Os.

The experiment therefore shows that the human binocular system is capable of picking up kinetic disparity, as distinct from the classical type of disparity, spatial disparity. In studies of monocular-kinetic space perception there is much evidence indicating that the monocular visual system is adaptively attuned to pick up the kinetic structure of the optic array directly (see, e.g., Gibson, 1957). The present study suggests that, for binocular-kinetic space perception, the binocular system is similarly attuned to pick up the disparity relation between the kinetic structures of the two optic arrays.

I would argue that a clear distinction should be made between binocular-kinetic and binocular-static space perception. It may be, for example, that binocular-kinetic information is picked up with a higher degree of precision than is binocular-static information. Thus the traditional view, derived from binocular-static studies, that the only importance to man of binocular stereopsis is for distances less than a few meters or so, may be incorrect; when movement is involved the effective range of binocular stereopsis may be considerably larger. Also, it is possible that a particular organism—whether it be animal, human infant, or human adult—may be incapable of binocular-static space perception, but may, nonetheless, be capable of binocular-kinetic space perception. This may be so, for example, if the organism's visual system were attuned to pick up primarily the kinetic structure of the optic

Fig. 2. The perceived motion of the vertical strip around a horizontal elliptical path: (a) left-eye film ahead—counterclockwise motion; (b) right-eye film ahead—clockwise motion. The strip was visible only when it was moving.

arrays at its eyes. Alternatively, the organism may have inadequate binocular overlap of its visual fields for binocular-static space perception; but when it moves, or when objects move, its binocular system may be capable of picking up the resultant binocularly time-shifted kinetic disparity information (see Note 1; also Lee, 1970).

Since there has been virtually no research done on binocular-kinetic space perception, the above ideas are only speculative; they are set down simply as suggestions for future research. In 1964, Gregory described an instrument—the stereoscopic shadow caster—which is suitable for such research, and recently the theory of the instrument has been developed and suggestions made as to its research uses (Lee, 1969). The instrument is quite versatile, being suitable for use

with human infants and animals as well as human adults. It has also been found to be well-suited to studying some of the temporal factors involved in binocular-kinetic space perception (Lee, 1970). Further studies using the instrument are currently in progress, and an attempt is also being made to develop more versatile methods.

REFERENCES

- GIBSON, J. J. Optical motions and transformations as stimuli for visual perception. *Psychological Review*, 1957, 64, 288-295.
- GIBSON, J. J. *The senses considered as perceptual systems*. Boston: Houghton Mifflin, 1966.
- GREGORY, R. L. Stereoscopic shadow-images. *Nature*, London, 1964, 203, 1407-1408.
- JULESZ, B. Binocular depth perception without familiarity cues. *Science*, 1964, 145, 356-362.
- KAPLAN, G. A. Kinetic disruption of optical

texture: The perception of depth at an edge. *Perception & Psychophysics*, 1969, 6, 193-198.

LEE, D. N. Theory of the stereoscopic shadow-caster: An instrument for the study of binocular-kinetic space perception. *Vision Research*, 1969, 9, 145-156.

LEE, D. N. Spatio-temporal integration in binocular-kinetic space perception. *Vision Research*, 1970, 10, 65-78.

NOTE

1. A recent experiment that A. G. Barrand and I have run at Cornell shows that man can utilize binocularly time-shifted kinetic disparity information in judging the distance of a moving textured surface seen through a vertical stationary slit in a screen, the slit being so positioned that no part of the texture is simultaneously visible to both eyes.

(Accepted for publication July 6, 1970.)