INSTRUMENTATION & TECHNIQUES

A technique for making realistic three-dimensional images of objects

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Two 151.8-cm-diam semicircular parabolic mirrors of optical quality are the essential components of an apparatus that creates highly realistic three-dimensional images of objects. The apparatus is being used to explore the relationship between vision and touch in infancy by creating a discrepancy between what is seen (a tangible-looking object) and what is felt. Previous attempts to study intersensory coordination in this manner have failed due to lack of realistic images. Other uses for the apparatus include the creation of illusory surfaces to study the development of expectations about the tangible surface properties of visible objects.

A dramatic, if common, procedure for studying intersensory relationships in human subjects involves creating a conflict between two senses and determining by verbal report which aspect of the sensory input dominates the perception of the stimulus event. A well-known experiment by Rock and Harris (1967) used this technique. Subjects viewed various objects through prisms that distorted the objects' sizes or shapes. When the objects were simultaneously seen through prisms and touched, subjects tended to report that the stimulus objects felt the way that they looked; that is, the visual sense was dominant in the perception of object characteristics in this visual/haptic conflict situation. To study the relationship between vision and touch in young infants, who cannot provide verbal reports, several researchers have attempted to create "virtual objects," which consist of three-dimensional images of objects that look palpable to the eye, and then to determine the infant's response when the image does not provide tactile feedback to the hand.

Several methods have been used to create such three-dimensional images. Bower, Broughton, and Moore (1970) had infants wear Polaroid goggles and view images projected by a Polaroid shadowcaster. Although Bower et al. reported that their young subjects responded with upset to the sensory conflict, the study has been criticized justly for confounding the effects of the intersensory conflict with the effect of wearing the

cumbersome Polaroid goggles (Bushnell, 1981). In addition, Polaroid images have abnormal parallax properties that could have alerted infants that they were not viewing real objects.

A second technique for creating three-dimensional images uses a Fresnel lens (Field, 1977). However, infants seem not to become upset or be startled by reaching into Fresnel images. Field noted that the images created by the Fresnel lens are less luminous than corresponding real objects, and also that their contours are less well defined, suggesting that the infant subjects can discriminate the virtual from the real objects. If the infants being tested can discriminate between virtual and real objects by visual properties alone, a basic assumption of the experiment is violated, and any results obtained are ambiguous. If virtual objects do not look like real objects, infants may well not be surprised if they do not feel like real objects either.

Here an apparatus for creating realistic three-dimensional images of objects that young infants and, for that matter, adults cannot visually discriminate from real objects is described. This apparatus allows researchers to examine aspects of intersensory coordination that up to this time have been inaccessible to students of infant development.

APPARATUS

The main component of the apparatus for producing the virtual objects consists of a World War II U.S. Government surplus search-light mirror.¹ Constructed of 1/8-in-thick steel, and plated with a nickel surface polished to optical quality, the original mirror measured 151.8 cm in diameter and was concave, with a depth of curvature of 20.2 cm. In optical terms, the mirror's shape is known as a paraboloid of revolution, and the

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mirror, as a parabolic mirror. To create the two reflecting surfaces necessary for making virtual objects, the mirror was sawed in half, and the resulting two sections were mounted in an aluminum frame and positioned so that they directly faced one another, with their outer edges in alignment and the flat, sawed edges on top. A 17.7-cm-diam semicircular opening was cut into both half-mirrors at the center position of the top edge. These apertures acted as focuses for creating and viewing virtual objects. As shown in Figure 1, a real object placed in the upper rear aperture results in the appearance of an inverted, three-dimensional image of that object in the front aperture. The inverted image is also reversed left to right.

The images created by two concave mirrors arranged as described above are both real and primary. An explanation of some of the characteristics of mirror images is necessary to understand these terms. Mirror images can be either real or virtual, primary or secondary. A virtual image is an image that appears to be located in space behind the surface of the mirror. The physical

locus of such an image is beyond reach, obstructed by the mirror surface in which it is reflected. This contrasts with a real image, which appears in front of the reflecting surface, situated in space between the observer and the mirror. Since the image sits in space in front of the mirror, the locus of the image can be reached for and explored manually, although with no resulting tactile sensation. A primary image is created by the mirror alone, and appears at the mirror's focal point. The image can be seen only at that particular location in space, and its location does not vary with the eye position of the observer. A secondary image, on the other hand, does shift position, depending upon the angle of view (like the image created by an ordinary flat mirror). A secondary image is not created by the mirror alone, but by the interaction of the reflective surface of the mirror with the retina of the eye. The images created by the parabolic mirror apparatus discussed here are primary because the positions of the images are constant, occupying their own positions in space, and real because the images stand out from the reflecting surface and

Figure 1. Exposed view of apparatus, frontal perspective, with real object upper rear and virtual object lower front.

their loci can be palpated by hand. Primary, real images are the best type of images for intersensory experiments because their visual appearance is most like that of the real objects of our everyday experience.

CONDITIONS OF IMAGE FORMATION

The placement of the real object relative to the rear aperture determines both the size of the image and its apparent position relative to the front aperture. The change in size of the image can be calculated by the formula $h' = [f/(f-x)]h$, where h' is the height of the image, h is the height of the real object, f is the distance between the two mirrors, and x is the distance of the real object in front of the rear aperture (see Figure 2).² The mirrors in Figure 2 are separated by their focal length, so that the focal point of one falls exactly in the aperture of the other.

From the formula, we see that when distance x is 0 (the real object is directly over the rear aperture), the size of the image is equal to the size of the object. An increase in distance x results in an increase in the size of

the image (h'). For example, a real object of height 5 cm, placed at a distance of 10 cm in front of the rear aperture (where $f = 76$ cm, the focal length of the mirrors) results in an image 5.8 cm in height. To calculate the size of an image when the real object is placed behind the rear aperture and the resulting image appears behind the front aperture, the same formula may be used, but negative values of x must be substituted in the formula. Thus, the resulting image will be smaller than the corresponding real object.

To calculate the distance y in front of the front aperture where the image will fall for a given distance x , the distance of the real object in front of the rear aperture, the formula $y = [x/(f-x)]f$ can be used (see Figure 2). In this formula, small increases in distance x result in small and somewhat greater increases in distance y . Thus, if a real object is placed 5 cm in front of the rear aperture, and the distance between the two mirrors is 76 cm, the image appears at a distance of 5.4 cm in front of the front aperture. The same formula can be used to calculate image position when the real object is placed behind the rear aperture by substituting negative values of x . We find that the most startling effect is obtained when the real object is placed just in front of the rear aperture so that the image is projected directly before the front aperture, suspended in space.

A second consideration in deciding on the placement of the real object and the corresponding spatial location of the virtual object concerns the angle of view over which the image can be seen. Taking as an example a stimulus object 5 cm in height and 2 cm in width (the size of one of the objects we use), we find that if this object is placed 5 cm behind the rear aperture and the eyes are approximately 38 cm above and 30 cm in front of the image, the angle of view is 85 deg, with the center-point of the arc at the midpoint of the image. To either side of this angle of view, the image is increasingly disrupted by the view inside the apparatus, and in particular by the lower rim of the mirror. A real object placed directly over the rear aperture creates an image that can be seen through an angle of view of 65 deg, and if the object is placed 5 cm in front of the rear aperture, the angle of view is reduced to 60 deg. Since the parallax properties of the images are normal throughout the angle of view, this stimulus position can be used with subjects whose head positions are relatively stable. Young infants, for instance, do not typically move their heads from side to side while exploring the images.

DATA COLLECTION

The infant's manipulations of the virtual objects are recorded with two videocameras. One, a Sony color videocamera (HVC 2200) is mounted on a superstructure of the apparatus, which is constructed such that it shields both the experimenter and the real object from view. The camera is focused through an opening in the rear panel 32 cm above and slightly to the left of the

Figure 2. The mirrors in Figure 2 are represented as being flat, full-length mirrors, rather than as curved, half-mirrors, to allow for the tracing of two light rays, C1 and C2, from the object to the reflected image. The tracings are based upon the facts that a light ray (such as C1) that arrives parallel to the surface of a parabolic mirror is reflected to the focal point of that mirror. Rays that are not parallel (such as C2) follow the rule that the angle of incidence (arrival) equals the angle of reflection. The letter h represents the height of the object, h' is the height of the image, x is the distance of the real object from the rear aperture, and y is the distance of the image from the front aperture. Angles a and a' , and d and d' , are equal (angle of incidence equals angle of reflection), and angles b , b' , e , and e' are right angles. Thus, triangles abc and $a'b'c'$ are similar, as are triangles def and $d'e'f'$. Line segments h and z are equal, since both are perpendicular to each of two parallel lines that are equidistant from one another, and h' and z' are also equal in length for the same reason. From these relationships, the formulas in the text can be derived.

rear aperture. This camera films the infant's face, torso, and arms. The second camera, a Panasonic WV 1500 black-and-white videocamera, is in front of the apparatus and offset to the left, and is focused on the front aperture. The infant is seated angled somewhat to the right of the front aperture to allow this camera to view the virtual objects. Both cameras are wired to a Thalner video splitter (TEL 20) so that the views from the two videocameras can be seen either simultaneously or in succession. A time/date generator clocks ongoing time during filming. A Sony SL 5800 videotape deck that has slow-motion and frame-by-frame viewing capability (allowing for a careful analysis of infant hand and body movements and facial expressions) is used.

The apparatus is currently being used to show both real objects and virtual images of these objects to 3-, 5-, 7-, and 9-month-old infants. Both familiar and unfamiliar objects are presented to ascertain the effect of familiarity on the infants' awareness of object properties.

Several other studies are planned. One makes use of illusory surfaces to study infants' understanding of texture. Infants are shown images of rough surfaces superimposed over transparent plastic surfaces that feel smooth and images of smooth surfaces that feel rough. Thus, infants feel a tangible object (or surface) while seeing the image of a different object. Unlike some other experimental situations noted in the literature (i.e., Lasky, 1977), in which the infant cannot see his or her hand while looking at a virtual object and reaching for a real object, here the hand is visible at all times. Since inability to see the hand is said to inhibit reaching in infants older than 5 months, a simultaneous view of both hand and stimulus is important to obtain adequate levels of reaching to the various stimulus conditions.

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NOTES

1. The purchase price of the mirror was \$4,500, a cost not viewed as excessive in light of the current cost of manufacturing a new mirror of equal size (estimated at approximately \$10,000). Less expensive possibilities exist, such as making a more thorough search of government surplus outlets than we had time or resources to make or making a mirror oneself with materials and instructions supplied by, for instance, Edmund Scientific (Barrington, New Jersey). For the purposes described in this paper, a mirror even half the size of the one mentioned here could be used to obtain realistic effects with small objects. The cost of such a mirror would be correspondingly less.

2. For ease of description, the mirrors in Figure 2 are represented as being flat. The formulas presented are derived from geometrical relationships that will be only slightly different if the actual degree of curvature of the mirrors is taken into account. For practical purposes, that is, for estimating the size and distance relationships between images and objects, these differences are not significant.

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