INSTRUMENTATION & TECHNIQUES

Peripheral vision monitor: Presenting displays at known positions in the visual periphery

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The peripheral vision monitor is an inexpensive device that ensures that visual stimuli can be successfully projected to a given extrafoveal location. The apparatus extinguishes the display lighting system when the observer attempts to view a region intended to be viewed only in peripheral vision, reinstating the illumination when that region is again in the peripheral field. This is achieved by focusing a small spot of light on the scleral-corneal boundary of the observer's eye and detecting the reflected light with a photocell and circuit. Illumination changes produced at the photocell are used to trigger the display lighting.

For studies of peripheral vision, it is important to guarantee that the information to be entered peripherally does not fall on the foveal retina. This may be arranged by presenting the peripheral stimulus tachistoscopically and having the subject view a foveal fixation point. Faithful adherence to instructions (to fixate centrally) is critical, and failure to comply, inadvertent or not, reportable or otherwise, is problematical, particularly if it is important that the subject never views the peripheral input with clear vision. An additional precaution is to record the subject's eye movements with the object of editing out those occasions when foveal fixation is inaccurate or inappropriate. Fail-safe recording of eye movements has been successfully used in some studies to allow the subject the opportunity freely to inspect a foveal fixation target while a critical peripheral stimulus is simultaneously available (Menzer & Thurmond, 1970; Townsend, Taylor, & Brown, 1971). This method has the advantage of not curtailing the life of the stimulus in such a way that the associated perceptual experience may be ecologically suspect. Eye movement recording may be combined with dynamic computer-controlled displays to provide more perceptual freedom and enable the competence and extent of extrafoveal regions to be explored more fully (McConkie & Rayner, 1975).

A novel and considerably less expensive solution to the problem of peripheral stimulus presentation is described. This method has been successfully applied in a research program (Ranklin, 1978) on the graphic details of text that skilled readers may detect extrafoveally, an area of increasing theoretical and practical interest in recent years (Hochberg, 1970).

The device to be described, the peripheral vision monitor, allows parts of a display to be viewed only in peripheral vision and prevents the same parts from being fixated directly in foveal vision. The objective is to enable stimuli to be presented at known positions in the peripheral visual field.

PERIPHERAL VISION MONITOR

The apparatus provides a means of controlling the display illumination so that the display lights are extinguished when the subject attempts to view foveally those parts of the display field that the experimenter intends to be viewed only in peripheral vision. The illumination is reinstated when those parts are again in the peripheral field. This is achieved by focusing a small spot of light on the scleral-corneal boundary of the eye and detecting the reflected light by a suitable photocell and circuitry; changes in illumination may thereby be used to trigger the display lighting. The current version of the apparatus consists of a face visor, a control unit, and a display unit.

Face Visor

The face visor consists of a plastic visor, such as that used as an eye protection in light industrial situations. It is of light weight and has hinged side bars that fit over the ears. Strong tape with Velcro fasteners are attached to the side frame and are taken around the back of the subject's head and fastened snugly. The plastic visor is bound with resilient sponge rubber to fit over the bridge of the nose and provides a firm and comfortable support. The visor is both simple and quick to fit to the subject and is stable because of the close fit to the head.

A small eye light and a photocell are carried on an

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Figure 1. Face visor showing eye light and photocell assembly.

adjustable assembly attached to the top metal frame of the visor (Figure 1). This eye switch can be positioned so that it may operate by reflected light from the temporal scleral-corneal boundary of either eye. The vertical position of this assembly is adjustable by Control A and can also be moved horizontally to positions nearer to or farther from the eye by Control B. The position of the eye switch relative to the temporal side of the eye is obtained by movement of the assembly in the Slot C, in which it is held firm by a nylon pressure pad. The angular disposition of the eye light relative to the photocell is adjustable by Control D; the swivel joint E allows the plane of the light and the sensor to be adjusted relative to the eye. These controls enable the assembly to be adjusted to fit individual subjects, and they need little further adjustment during an experimental session with a given subject.

The eye light is a small tungsten source focused by a short focal length lens (12-m^{-3} microscope objective). The lamp is positioned at two focal lengths from the lens, so that when the lens is 24 m^{-3} from the eye

surface, a sharp image of the lamp filament is projected on to the eye surface. The size of the image is about 4 m^{-3} high and 1 m^{-3} wide, and the lamp is oriented so that the image on the eye surface is at right angles to the horizontal movement of the eyes. The lamp is fitted with a brightness control.

A small red light-emitting diode (LED) is fixed in the center of the head band of the face visor. This is used to monitor the head position.

Control Unit

The signals from the eye switch are fed into the circuit shown in Figure 2. The basic circuit is a variable-gain differential amplifier with balance and gain controls to compensate for ambient light levels and differences in reflected light levels from the eye surfaces. The output from the amplifier is fed into a Schmitt trigger to provide on-off switching to trigger the display light drive circuit. Two "inhibit" circuits are shown that prevent the circuit's operating until the subject's head is correctly placed in the display unit.

Display Unit

The display unit is essentially a light-tight box .43 m high x .45 m wide x .51 m deep. Displays of stimuli are shown at the rear, illuminated by quick-start fluorescent lamps.

The subject's head is kept in position by a headrest and a chin rest at the front of the box. These are positioned so that the head is slightly bent forward and the chin is supported comfortably. The headrests have two side pieces that can be adjusted to fit comfortably up to the temples. In this position, the forward weight of the head against the headrest closes a microswitch that enables the display light circuit. The release of this switch by unauthorized head movements inhibits the onset of the

Figure 2. Control circuitry for peripheral vision monitor.

display lights. In addition, the small red LED fixed to the center of the headband of the face visor illuminates a photoswitch (LAS 15) attached to the center of the headrest. This is adjustable, so that when the subject's head is in the correct lateral position, the display light circuit is inhibited unless the photoswitch is fully illuminated by the LED. Thus, both the microswitch and the photoswitch have to be activated before the display light circuit can be operated by the light reflected from the eye onto the photocell in the eye switch.

Calibration scales are shown at the back of the display unit in the same plane as the displays in use. One convenient method for graphic material is to use a horizontal series of symbols similar to those used as experimental stimuli. For example, in a reading experiment, alphabets typed in a single line with double spacing have been used to ascertain the point in the display at which the display light is extinguished. These "scales" were also used as the adaptation field, and they allowed the checking of the calibration between experimental trials.

Since the display material is viewed directly, its distance from the subject can be readily manipulated. The current model of the peripheral vision monitor includes a provision for this. The display lights need to be mounted on the screen bearing the display stimuli.

OPERATING PROCEDURE

Experiments are carried out in a darkened room, and the criterion for the ambient light level is that the subject be unable to detect any feature of a stimulus display in the apparatus during display light offset.

The face visor is fitted to the subject while he is standing facing the experimenter and looking straight ahead with his head bent slightly forward and downward. The position of the eye light assembly is adjusted so that (1) the light spot rests on the eye at the scleral-corneal boundary to the right of the subject's eye (if the apparatus is being used to monitor the right peripheral visual field), (2) the plane of the eye light and photocell assembly is effectively normal to the surface of the eye, and (3) the incident light path from the eye light, if produced, would pass through the center of the eyeball. In this way, a horizontal movement of the eye perpendicular to the plane of the eye light and the photocell produces a movement of the light spot across the scleral-corneal boundary. The coordination of these two lateral displacements, of eye and light spot, is used to determine whether the adjustment is satisfactory.

When fitting the subject into the headrest and chin rest, the head is placed in a slightly forward position, with the eye light assembly a fraction below the line of regard. This serves to leave a relatively large area of the sclera clear of the eyelids. If the eyelids are close to the light spot, the signal-to-noise ratio of the reflected light tends to be degraded.

CALIBRATION OF PERIPHERAL POSITION

The calibration of the peripheral position of stimuli within the display space is achieved by use of a horizontal scale. As the subject scans the display, the eye switch will extinguish the display lights at a particular position on the scale. This occurs when the junction of the sclera and the cornea crosses the leading edge of the light spot and the light reflected onto the photocell is reduced in intensity. In experiments investigating the right visual peripheral field, the display is illuminated when the eye scans the left of the display, but as the subject scans to the right, the eye switch operates as the eye rotates through the critical position. In experiments using typescript, the horizontal scale has consisted simply of typed alphabets similar to those used in the displays. Subjects read through the alphabet scales from the left until the display light extinguishes.

If the offset position is in error, the experimenter may adjust the controls on the eye switch assembly, but if the error is small, an alternative procedure is to instruct the subject to turn his head slightly in the headrest to compensate for the error. When the correct position is attained, the position of the photoswitch in the headrest is repositioned to inhibit the circuitry should the head be turned out of the new position.

As a precautionary check, all subjects are encouraged at a preliminary stage to try to "beat the switch" by making ballistic eye movements. When the apparatus is correctly set, this has proved to be nonproductive, and subjects cannot foveally capture stimuli intended to be peripheral.

The calibration scales are presented between each experimental trial so that the accuracy of light offset may be checked. Subjects may also be encouraged to learn how their eye movements control viewing conditions. Many are successful, and some appear to gain very precise control of eye position in these conditions. Since it is manifestly impossible to ensure complete head immobility without uncomfortable constraints that limit experimental procedures, the cooperation of the subjects is helpful. Subjects may rest between trials while remaining in the apparatus with the eyes closed and display lights on.

The preliminaries (fitting and calibration) and up to 144 trials may be completed in a 1-h period with a nonautomated procedure. We generally remove the subject from the apparatus after a maximum of 48 trials.

LATENCY OF OPERATION

Measurements made of the fall time of the fluorescent tubes used for the display lights indicate a latency of 15 msec from 100% to 0% light output, which agrees with the data given in the technical literature. Similarly, the onset of the photocell is less than 2 msec. Both of these estimates are conservative.

The shape of the eye surface contributes to the latency of the apparatus response. At the junction of the sclera and the cornea, assuming that both are circular arcs in the horizontal plane, the angle between the normals to these surfaces is approximately 13 deg (computed from Brown, 1965). Since the photocell is illuminated by scleral reflection, the effect of turning the eye horizontally is to cause the light beam reflected from the eye to move off the sensor at a greater angular velocity than the angular velocity of the eye. This effect is enhanced by the shape of the sensor's active area and the shape of the small spot of light projected onto the surface of the eye. Both are rectangular in shape, with their long axes perpendicular to the angular rotation of the eye as it moves laterally, so that advantage is taken of the sensor's greater sensitivity at higher levels of illumination. Also, there are irregularities at the scleral-corneal junction. The conjunctiva is present, and if this mucous membrane were large enough to influence the situation at all, it would have the effect of diffusing the reflected light as it traverses from the sclera to the cornea. Measurements using an artificial eyeball indicate that the sensitivity of the apparatus is sufficient to detect movements of between .25 deg and .5 deg with near certainty.

Brown (1965) reported that the reflectivity of the iris is approximately 2.5%, so that the light transmitted through the cornea to the iris is largely lost, whereas much of the light incident on the opaque sclera is reflected or scattered. Measurements have shown that the overall latency of the apparatus is 40 msec at worst. Latour (1962) and Volkmann, Schick, and Riggs (1968) report that the sensitivity of the eye is reduced not only during an eye movement, but also for 50 msec before the movement begins and for 50 msec after the movement has been completed. In experiments performed with the apparatus, the subject has scanned letter or word sequences presented foveally and the eye switch has operated as the eye rotated through the calibrated critical position. Since vision is impaired during this movement and the light output has started to fall at some point within this period, the two effects may be expected to summate to reduce the visual input. Moreover, the latency of the apparatus is less than the latency of reduced visual sensitivity, so that the display light output reaches zero before sensitivity recovers.

However, postsaccadic suppression is found with stimuli at threshold luminance. So, with suprathreshold displays in the periphery, the effect may not preclude the pickup of information beyond the offset boundary. In fact, the point in the eye's trajectory in time and space at which the display illumination terminates depends on how fast and how far it is moving when the boundary is passed. Because we are not yet able to record eye movements while the peripheral vision monitor is in use, we have no direct information on the

extent of this problem. But we can use data from other sources to estimate some limiting conditions.

The conditions of interest involve saccades initiated so that the boundary is traversed while the eye is in flight. Yarbus (1967) found that the duration of a saccade in seconds is given by $T = .021\alpha_0^{.4}$, where α_0 is the saccade amplitude in degrees, and that the relation between angle of rotation (α deg) and time taken (t sec) is $\alpha = .5[\alpha_0(1 - \cos\pi t/T)]$. It is possible therefrom to estimate the eye's landing position (and hence the visual angle gained) for a given saccade amplitude and to estimate the length of the corresponding period during which the eye is fixated on the unintended (by the experimenter) peripheral location. It is, for example, possible for a subject to gain a 30-msec view of the peripheral target .5 deg beyond the boundary by initiating a 2-deg eye movement 1.5 deg in advance of the boundary. More dramatically, although perhaps less usefully, the subject could gain as much as 5 deg for 14 msec by starting a 10-deg saccade some 5 deg before the boundary.

It is apparent that similar problems are experienced by any method in which display illumination or content changes at a critical boundary are subject to some delay (cf. McConkie & Rayner, 1975). However, these limitations are unlikely to be serious in practice for all but the most perverse of subjects, since the procedure may be designed to persuade individuals to approach the offset boundary with suitably small saccades (see Figure 3). Moreover, as observed above, subjects asked to try to beat the eye switch received the impression that they could not fixate on the peripheral material. Beyond this, the answer is to reduce the apparatus lag to a trivial amount by using more than one photodetector (as in the research of Noton & Stark, 1971) or by using infrared monitoring (Young & Sheena, 1975).

IMPROVEMENTS

The display technology can be improved in at least two ways: The latency of operation can be decreased by using faster components and, perhaps more critically, a back-projection system can be incorporated so that the display disappears whenever illegal eye movements occur, at the same time preserving display illumination. This can be achieved by using the eye switch to control whether critical information or a blank display is being projected. This has the advantage of avoiding unwanted rapid changes in illumination level.

APPLICATIONS

The peripheral vision monitor has been used to investigate the ability of fluent readers to pick up graphic information from the right visual periphery (Ranklin, 1978; Ranklin & Barber, Note 1). Various tasks that illustrate typical applications of the apparatus in

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Figure 3. Examples of displays for use with the peripheral vision monitor (as in Ranklin, 1978). The tasks entail (a) judgment of word-length patterns and (b) discrimination of ascending vs. descending word-length patterns. The apparatus is set to extinguish the display at the position marked by the asterisk, and the subject reads aloud the material to its left prior to making a response about the peripheral display.

reading research have been used for this purpose. In some studies, the subject named a horizontal series of words or letters, seen foveally and terminating at the offset point, and was asked to make judgments about the nature of the linguistic material presented at the same time but extrafoveally. For instance, fluent readers have been asked to judge the word-length pattern of peripheral letters as in Figure 3 (a cue that has been proposed as having syntactic significance; Ranklin, 1978). These experiments were replicated using tachistoscopic presentation, and performance for the visual angles (≤ 6 deg) used, which were a good deal more restricted than those possible in the peripheral vision monitor (i.e., up to 14 deg), agreed very well with data obtained using the monitor. Other experiments have shown that subjects can discriminate between ascending and descending word-length sequences seen peripherally (Figure 3). The detectability of punctuation cues at distances up to 51 letter spaces (12 deg) beyond the offset point has also been examined.

REFERENCE NOTE

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