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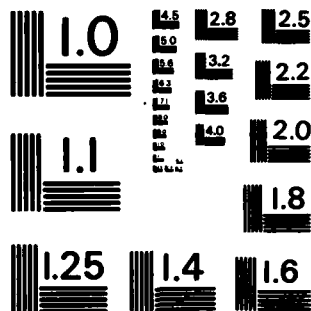


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SPATIAL LOCALIZATION IN STRABISMIC OBSERVERS

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10 JUNE 1983

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DISCUSSION

The individual perceiver is not directly informed about the actions of two of the three muscular systems which operate to optimize various properties of his retinal image for visual perception. Pupil size and lens shape are themselves controlled within closed loops in which particular attributes of the retinal image (and perhaps of perception itself) serve as the basis for servo signals: -- some aspect of the quantity of illumination is used to control pupil size in the interest of optimizing the tradeoff between quantum catch and image quality; some function of image clarity is employed to control lens shape. But direct information about neither pupil size nor lens shape enters visual perception at all. For example, the accommodative state does not provide a cue to depth perception -- although, in principle, it could -- nor is pupil size even a reasonable possibility as a cue to perception for anything at all.

This lack of information regarding the actions of the pupil and lens is in marked contrast to the eye movement control system, where quite a different story holds for the consequences of the actions of the extraocular muscles. Although for some classes of eye movements the extraocular muscles also may act under closed loop control, direct open loop information about the action of the extraocular muscles not derived from effects on the retinal image are essential for visual perception, if only for the obvious reason shown in Figure 1 -- namely, that an observer foveating the visual target (in a) would have an identical change in retinal image location produced by target movement through angle θ (in b) and by an eye movement through angle θ (in c). It is essential that the observer perceive matters differently in (b) and (c), and for this purpose it has seemed essential to have a channel of information that can signal the change of eye position separately from the channel of information that signals retinal location. In the same vein, it is also desirable that the observer be able to perceptually derive the spatial location of visible objects from information regarding their retinal image location. But, this too cannot be done from retinal image location alone any more than one can derive the location of an object in a room from the location of the image of the object on a film's image of the room taken by a camera. However, if the orientation of the camera relative to the room is also given as a separate piece of information, it becomes possible to derive the location of the object relative to the room.

Thus, it has seemed obvious that our visual localizations of visible objects must be obtained by combining information about retinal image location (RI) and extraretinal information about eye position relative to the orbit (EEPI). The particular combination of RI and EEPI that relates the two by a neural subtraction process is the Cancellation Theory and is represented in Figure 2.

(Although it will not be pursued here, it is worth noting that Cancellation Theory comes in three forms (Figure 3): Inflow Theory puts the source of EEPI in receptors in the orbit; Outflow Theory puts the source of EEPI in the command to turn the eye, and the Hybrid Theory puts the source in the orbit but modulates the inflow by means of outflow. Which of these versions is correct is not yet known (Matin, 1972, 1982).

In last year's Final Technical Report (Matin, 1982a) I described how we were able to conclude -- largely from our experiments with experimentally paralyzed eyes of human observers -- that the cancellation mechanism is the basis for visual localization in darkness, as well as a most important basis for intersensory localization in a normally illuminated environment and in darkness, but that in a normally illuminated environment visual localization was not itself normally influenced by the cancellation mechanism. Instead, in a normally illuminated environment the involvement of the cancellation mechanism in visual localization was suppressed.

Thus, in order to study the relation of EEPI and the cancellation mechanism to spatial localization in the absence of such suppression, the situations of first choice include (1) studying visual localization in darkness; (2) studying intersensory localization in darkness; (3) studying intersensory localization in a normally illuminated environment. We have studied all three. In addition, some specific theoretical interests regarding the relation of cancellation to localization has led us to investigate localization in strabismic observers. These interest include (1) an attempt to determine

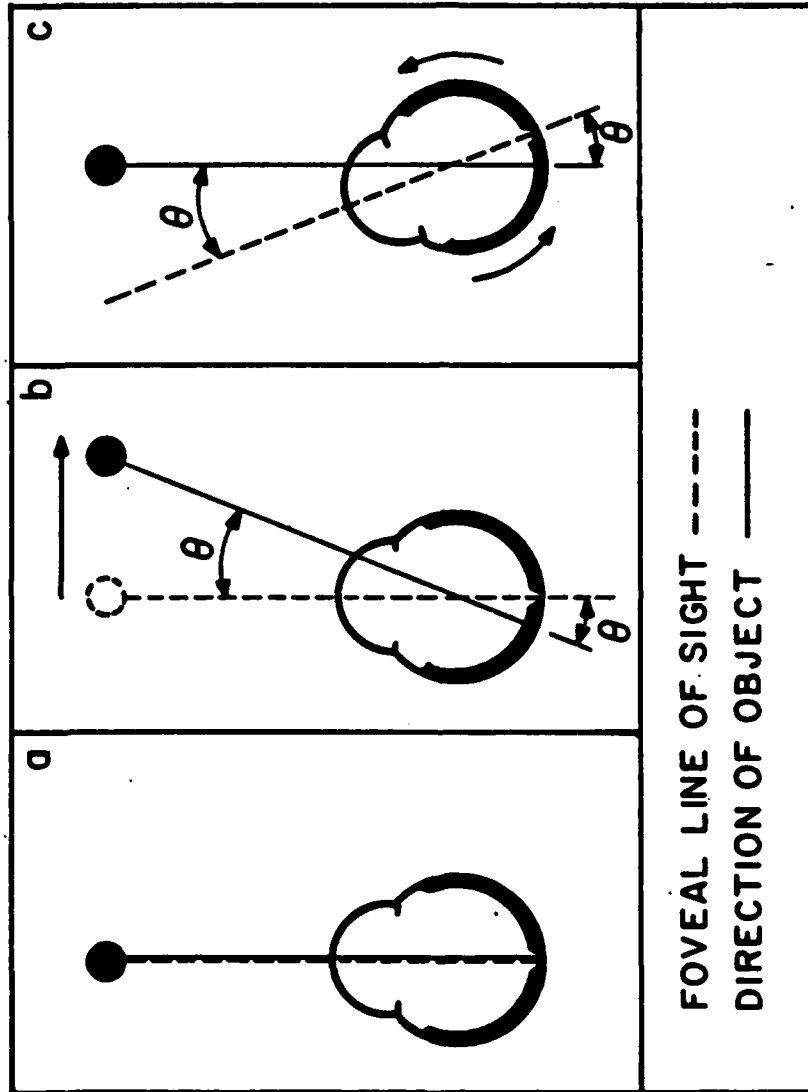


Figure 1. Identical Shifts In Stimulus Retinal Location Are Produced By An Ocular Rotation Or Stimulus Displacement Through An Angle

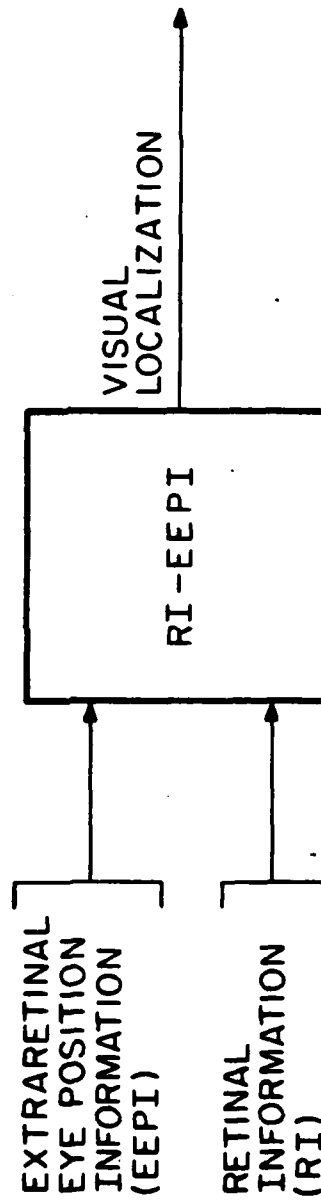
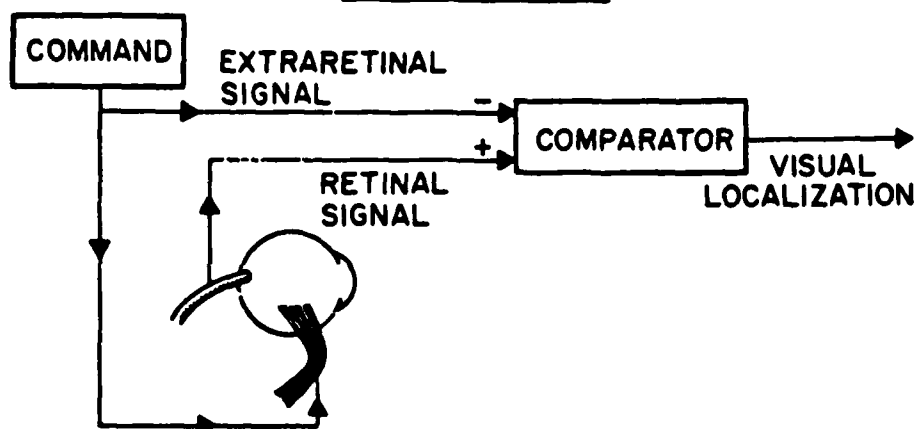
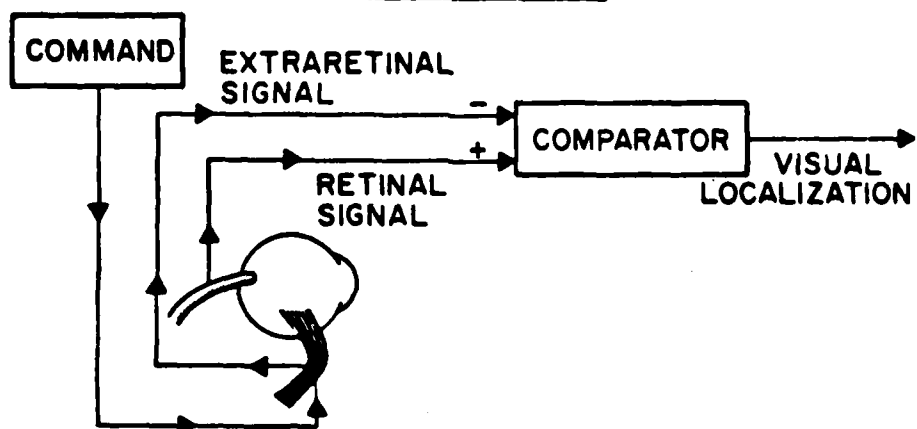


Figure 2. Cancellation Model

OUTFLOW MODEL



INFLOW MODEL



HYBRID MODEL

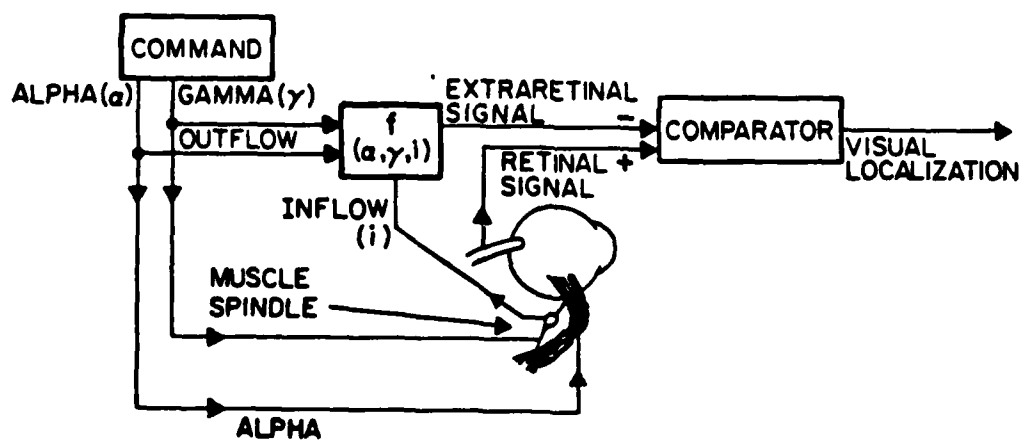


Figure 3. Three Versions Of Cancellation Model

from psychophysical experiments which of the two neural circuits (in Figure 4) for cancellation-mediated localization was true, and (2) an interest in determining which of the two models in Figure 5 (Figure 5a; Figure 5b) described the way in which EEPI was involved in the determination of localization with the two eyes. (3) An additional interest that led us to work with strabismic observers was concern with the possibility of flexibility and/or adaptation in the relation between RI and EEPI. Strabismic observers provide a singularly useful anomaly for dealing with these three focal interests. The experiments to be described below deal particularly with (2) and (3).

Figure 6 shows the strabismic observer (viewed from above) monocularly viewing a light with the left eye when the right eye is occluded (left side of figure), and also monocularly viewing the same light with the right eye when the left eye is occluded (right side of figure). The angle α is the angle of strabismic deviation. If the EEPI employed in localizing the light for each of the two viewing conditions in Figure 6 is the same (model in Figure 5a; "localization with unitary binocular EEPI")-the difference in localizing the light between the two conditions should be equal to the difference in ocular posture between the two conditions -- that is, equal to the angle α . Strabisms with different deviations should thus show differences in localizations between the two eyes that should be simply related to the size of the strabismic deviation. If localization was mediated via the "unitary binocular EEPI" as in Figure 5a then this difference in localizations between the two eyes should hold when the visual target A is presented at any eccentricity, not just in the median plane as shown in Figure 5.

On the other hand, if the EEPI employed in localizing the visual target in Figure 6 was not the same when localization was with the left eye viewing as when localization was with the right eye viewing -- that is, if EEPI is separate and different when viewing with one eye as compared to when viewing with the other eye (model in Figure 5b; "localization with independent monocular EEPI"), then the difference in localizations with the two eyes of a strabismic observer need not be equal to the strabismic deviation. Specifically then, if the difference in localizations between the two eyes of strabismic observers is unrelated to the magnitude of the strabismic deviation then one could conclude that EEPI employed for localizing with one eye was independent of EEPI employed for localizing with the other eye. A result in which the relation between strabismic deviation and localization difference between the two eyes was neither complete nor entirely absent would indicate some linkage between the EEPI employed when the left eye was viewing alone and when the right eye was viewing alone.

As a means of measuring visual localization we employed a localization match between the fixated visual target and a sound whose location within the horizontal plane was variable. This localization match was carried out by each of 23 strabismic observers with monocular viewing with each eye at each of three gaze eccentricities determined by the experimental placement of the fixated visual target (12.5 degrees to the left of primary position, primary position, and 12.5 degrees to the right of primary position).

Figure 7 shows the results for one normal observer (MR, upper left panel; measurements were made at 5 gaze eccentricities in his case) and three strabisms; the figure plots the location of the matched sounds against the eccentricity of the fixated visual target, with the main diagonal indicating the focus of veridical settings. Table I shows a characterization of the 21 strabisms for whom we have at least complete preoperative data (each of these strabisms was operated on and most were available for postoperative testing -- see below).

Figure 8 shows the match at each of the three gaze eccentricities for each of the ten comitant strabisms on whom complete pre- and postoperative measurements were made. The main diagonal plots the prediction from the model with unitary binocular EEPI (difference in localizations between the two eyes should be equal to the strabismic deviation). The dashed horizontal line plots the prediction from the model with independent and different monocular EEPI for each eye. The results fall along a best fit line with a slope of +.22, very far from the unitary EEPI model. Further indication of the failure of the results to support the unitary EEPI model is the fact that there was no regular order to the localization errors at the three gaze eccentricities across observers. Difference between the two eyes in setting of a visual target to the median plane also showed no systematic relation to the magnitude of the strabismic deviation (best-fitting slope = +.05).

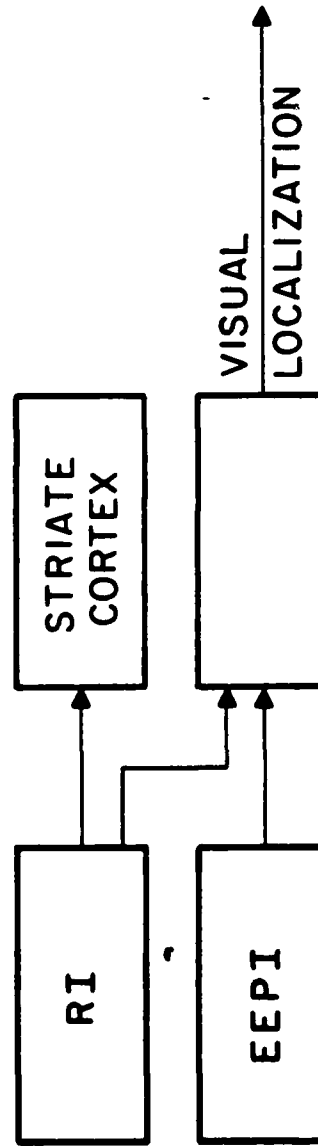
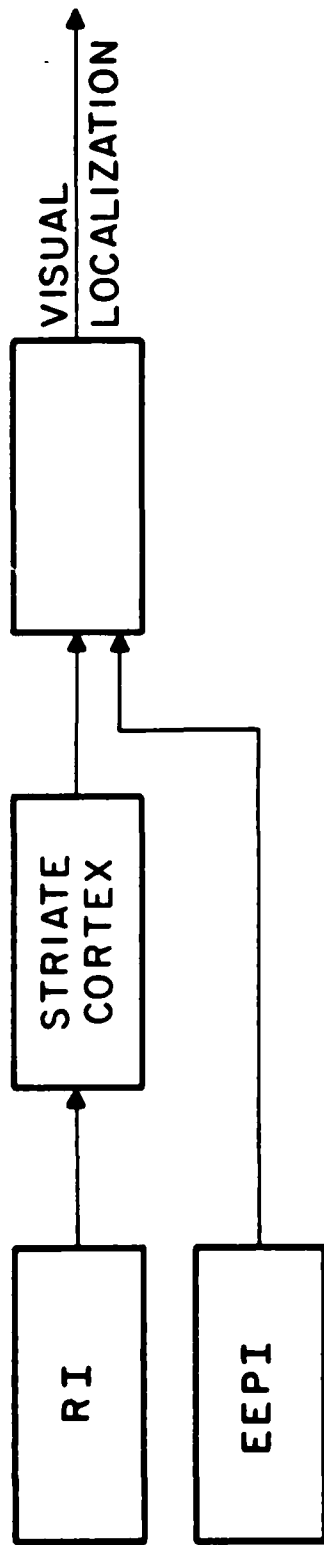
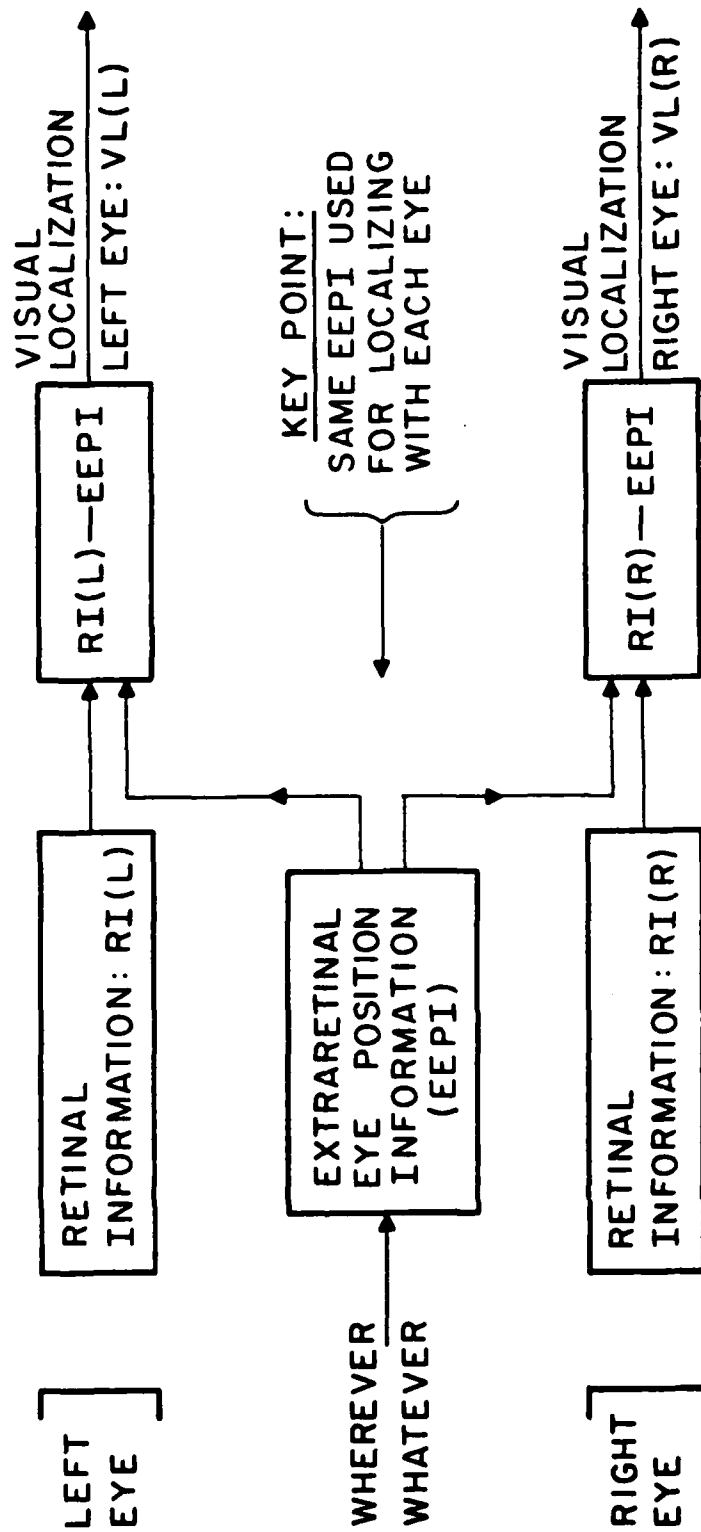


Figure 4. Two Possible Neural Circuits By Which Cancellation Is Mediated

LOCALIZATION WITH UNITARY BINOCULAR EEPI



IF $RI(L) \neq RI(R)$, THEN $VL(L) \neq VL(R)$.
SPECIFICALLY: $RI(L) - RI(R) = VL(L) - VL(R)$.

Figure 5(a). Cancellation With Unitary Binocular EEPI

LOCALIZATION WITH INDEPENDENT MONOCULAR EEPI

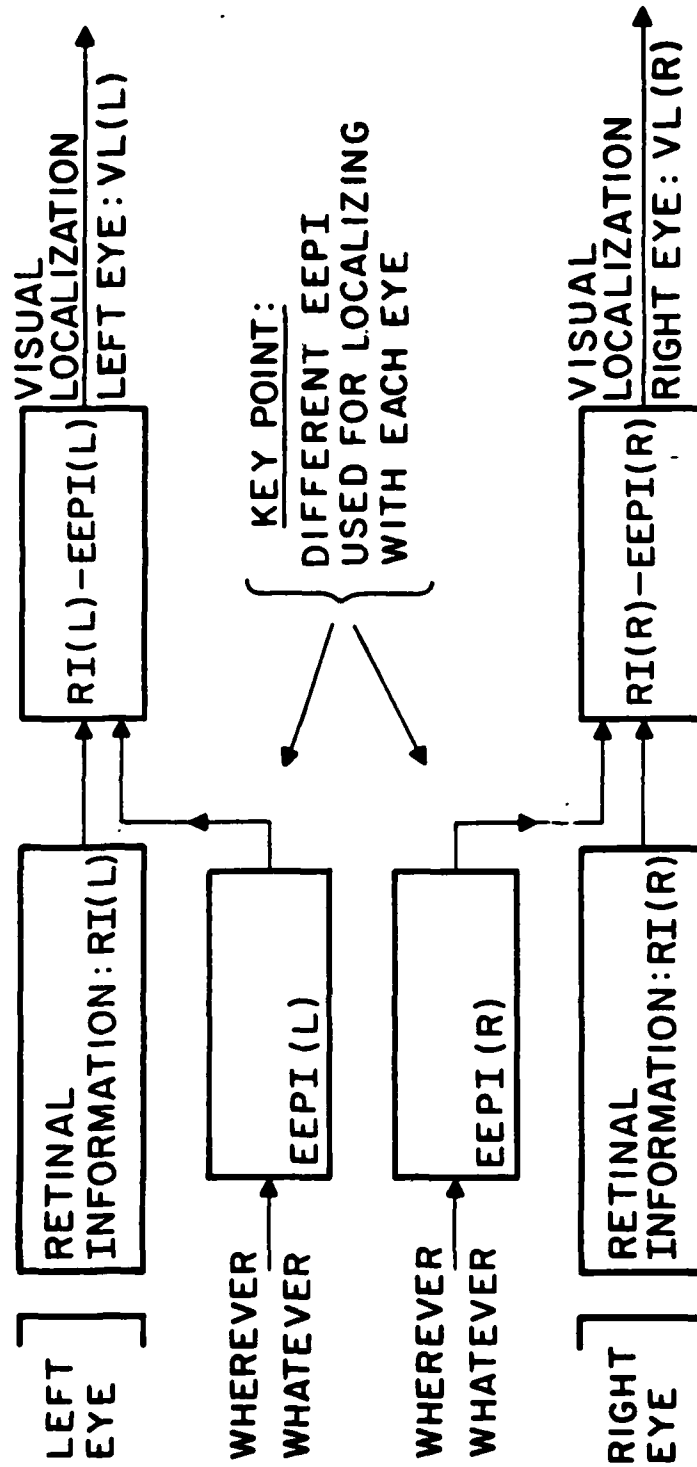
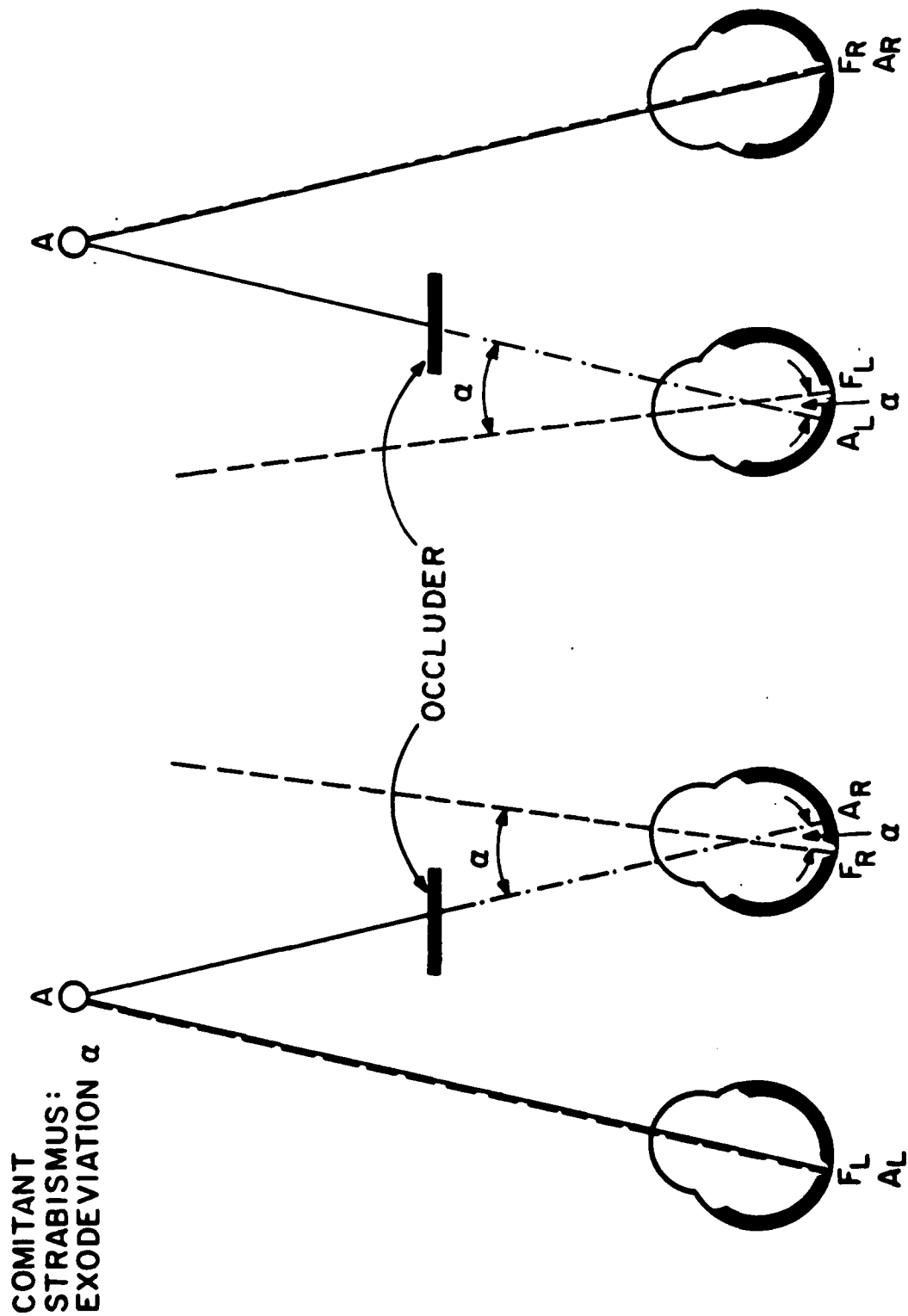


Figure 5(b). Cancellation With Independent Monocular EEPI



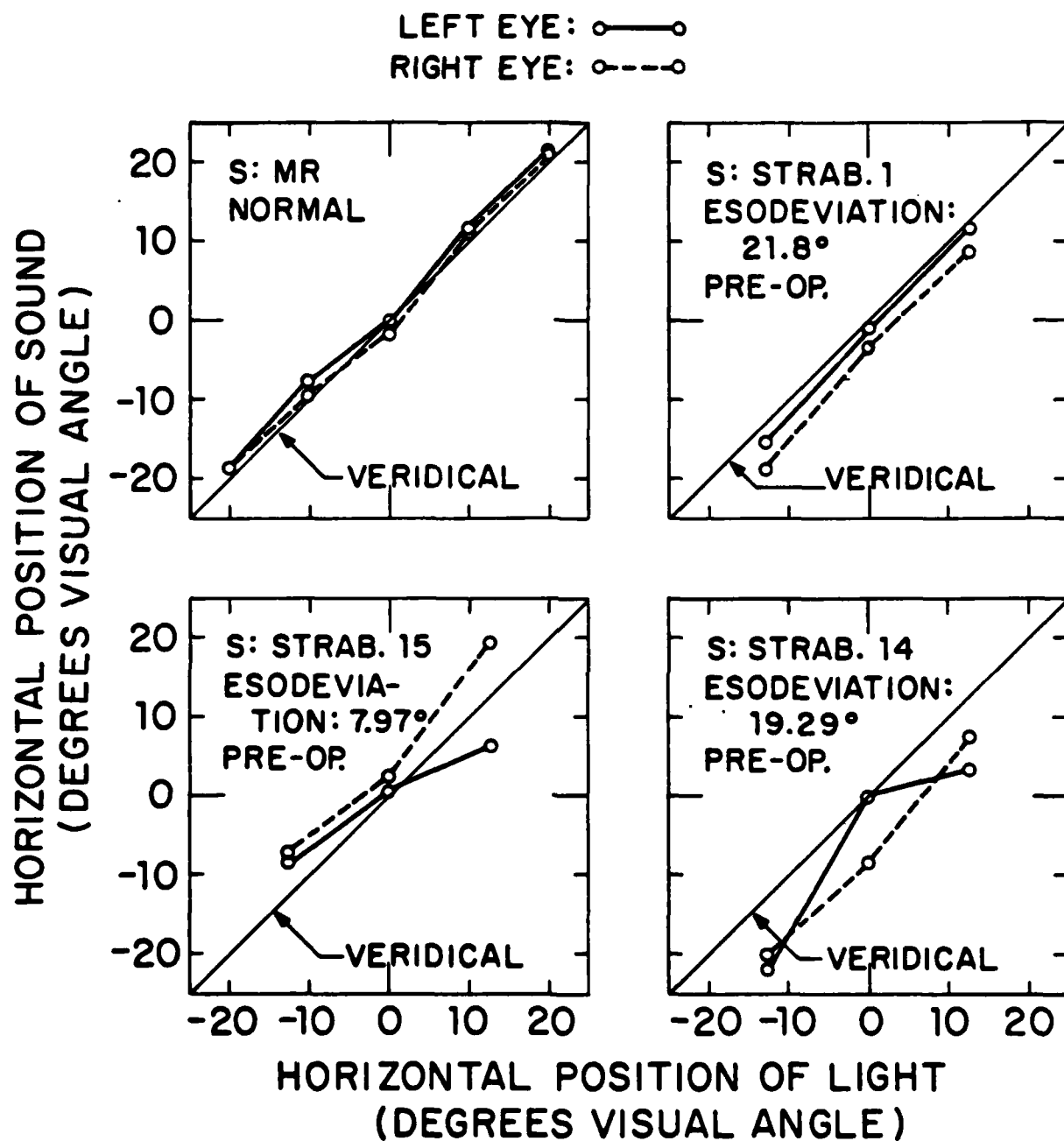


Figure 7. Match Of Horizontal Location Of A Sound To Location Of A Foveally Fixated Light For Each Eye Separately Viewing Monocularly For Each Three Strabismic Observers At Each Of Three Gaze Eccentricities And One Normal Observer At Each Of Five Gaze Eccentricities

Table 1. Characteristics Of The 21 Strabismic Observers

n = 21		DEVIATION	COMITANCE	
			COMIT.	INCOMIT.
OPERATION	ONE EYE	ESO	4	1
		EXO	3	2
	BOTH EYES	ESO	4	1
		EXO	3	1
		MIXED	-	2

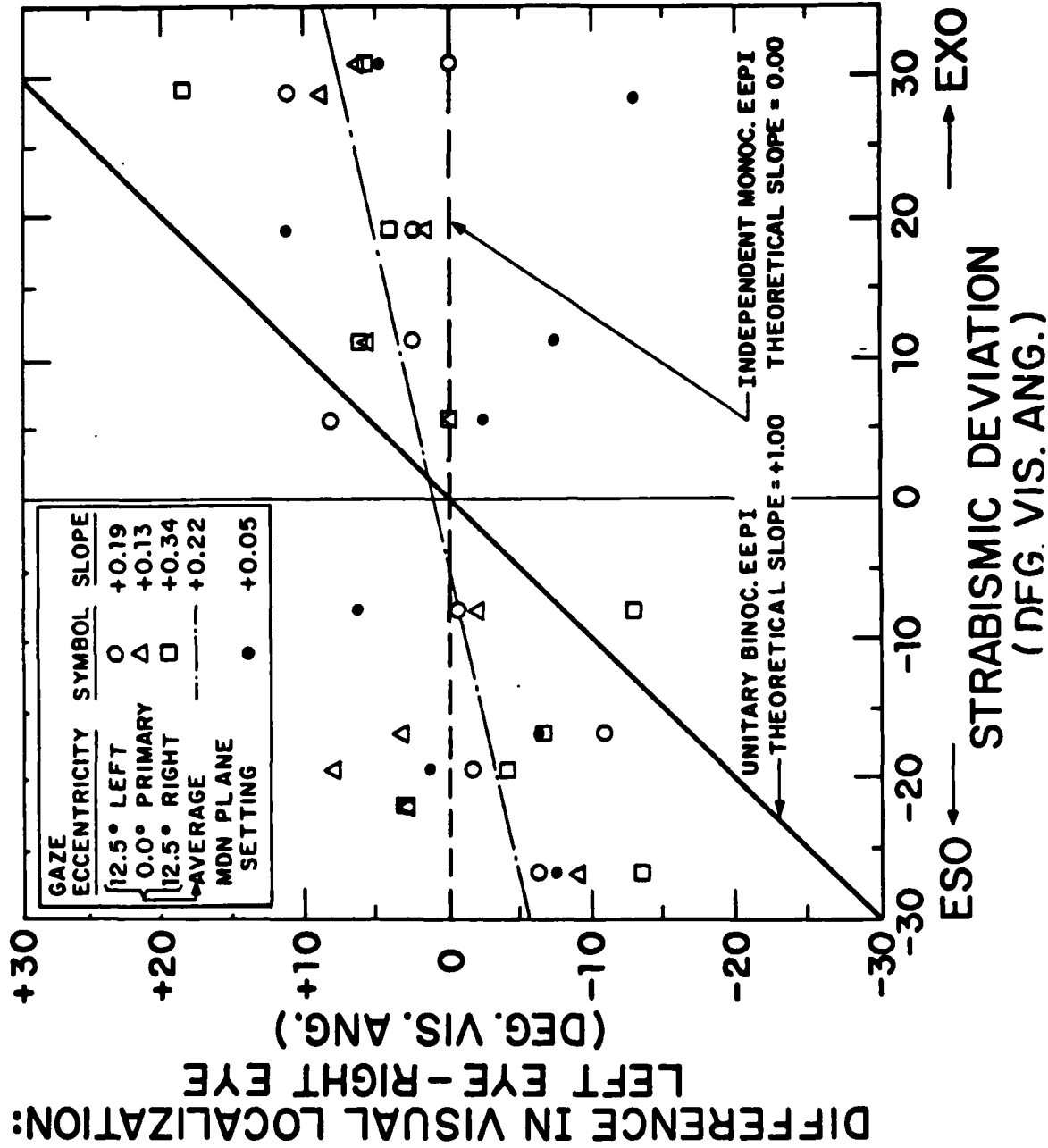


Figure 8. Preoperational Results For 10 Comitant Strabismic Observers, Showing The Left-Right Eye Difference In Localization Plotted Against The Magnitude Of The Strabismic Deviation.

Figure 9 repeats Figure 7 but also adds the postoperative results for the three strabismic observers. The postoperative results were obtained within 48 hours following the strabismic surgery. Postoperative measurements are not systematically different from the preoperative measurements for the strabismic observers in Figure 9; nor were systematic differences obtained for any of the other operated strabismics. Figure 10 displays the change in the difference in localization (change in left eye-right eye difference). The change was not systematically related to the original strabismic deviation (slope = $-.03$) which itself was approximately equal to the surgically produced ocular position change. These results either imply the operation of an inflow mechanism or a rapid recalibration of EEPI. I strongly believe that rapid recalibration has occurred; this does not at all, however, say anything about the presence or absence of an inflow mechanism.

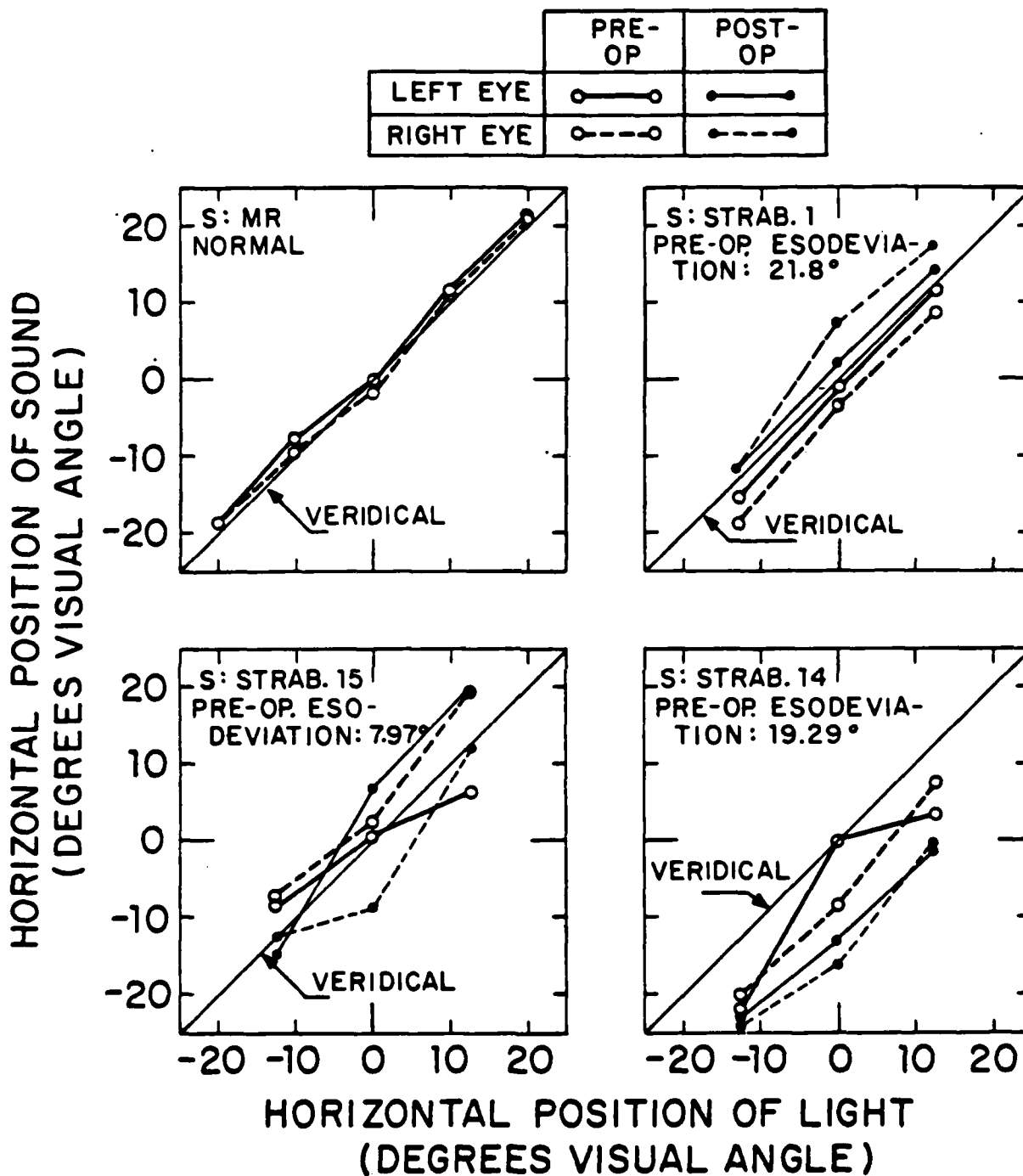


Figure 9. Same As Figure 7, But Also Shows The Postoperative Measurements For Each Eye

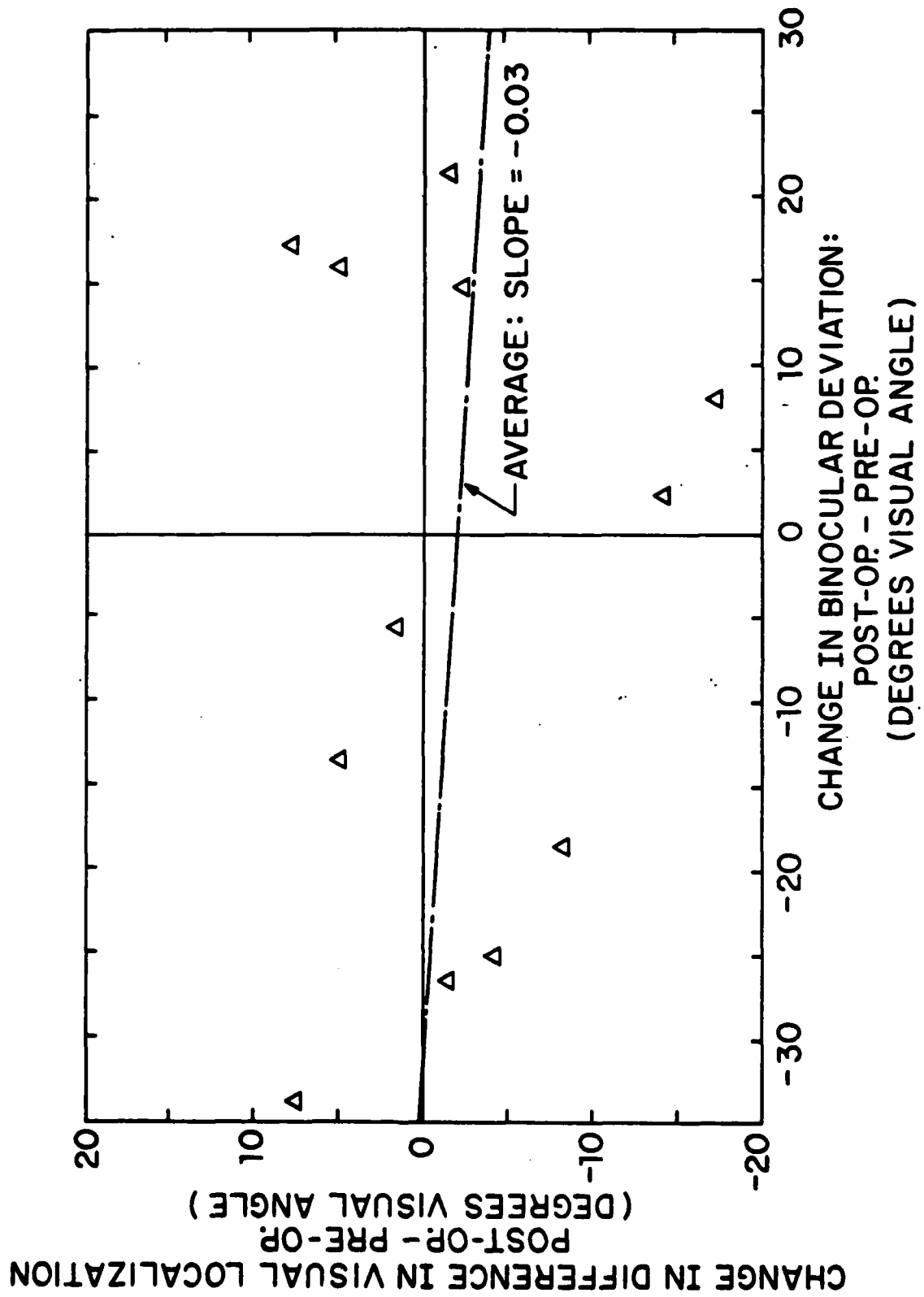


Figure 10. Postoperative Minus Preoperative Difference in the Left-Right Eye Difference in Localization Plotted Against The Preoperative Strabismic Deviation

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