Object localization in children with strabismus: in the median plane and unchanged by surgery

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Purpose. Previous studies have shown that there are spatial localization shifts after horizontal strabismus surgery when a patient performs an open-loop pointing task. After monocular enucleation, an adult will also show a shift in the pointing response. Other studies have shown that in children who underwent enucleation, the egocenter location shifts toward the remaining eye. Is the pointing shift after surgery in children with strabismus the result of a shift in egocenter location?

Methods. Using a modified Roelofs' method for measuring the egocenter, eight children were tested before and after horizontal strabismus surgery to see if there were any shifts in egocenter location. One control group consisted of six children undergoing surgery for correction of vertical strabismus in which the horizontal muscles would be unaltered.

Results. Presurgery measurements of egocenter location in the people with strabismus were the same as those found in the other control group of 12 normal children. Postsurgical measurements of eye position showed horizontal rotations of 14.5° for the horizontal group and 2.4° for the vertical group. Egocenter measurements showed no postoperative shift for either strabismus group.

Conclusions. Thus, the pointing shift seen in the previous studies is not from a shifting egocenter location but from a change in the registered position of the eye in the orbit. Invest Ophthalmol Vis Sci 1993;34:2990-2995.
shift with the remaining eye looking at the targets, measured soon after the other eye was removed. Because we know that the egocenter shifts toward the remaining eye in those who have undergone enucleation, could the postsurgical pointing shift in people with strabismus be caused by a shift in egocenter location as well?

We therefore wanted to answer two questions about the location of the egocenter in children with strabismus. Would these children, before treatment, have the same egocenter location as children who underwent enucleation even though people with strabismus have some input from each eye? Would strabismus surgery cause an immediate shift in the location of the egocenter? To study these questions, we tested children before and after strabismus surgery and children with normal binocular vision.

**MATERIALS AND METHODS**

We tested 12 children before and after horizontal strabismus surgery. As a control for the influences of the anesthetic and other surgical procedures, we tested 6 children before and after vertical strabismus surgery in whom no changes in horizontal eye position were expected. As a second control group, 12 children with normal binocular vision were tested on one occasion. The mean age of the horizontal children with strabismus was 10.4 years (SD = 3.8), and for the normal children it was 10.4 years (SD = 3.5). In the horizontal group, six patients had previous surgery on the "to be operated eye" (5 esotropes and 1 exotrope who initially had been esotropic), and there were six patients who had no previous surgery (3 esotropes and 3 exotropes). In the vertical group, the mean age was 11.1 years (SD = 2.6). Three of these patients had previous surgeries to correct for horizontal deviations (one also had a dissociated vertical deviation with right superior oblique palsy and another had superior oblique palsy), and three patients had no previous surgeries, but two of these patients had superior oblique palsy. None of the people with strabismus had any paralyzed horizontal eye muscles, and the vision of each child was at least 6/12 in the worst eye, and all were able to perform the tasks without correction. There was no information available about their retinal correspondence. The tenets of the Declaration of Helsinki were followed, and the research proposal was vetted by The Hospital for Sick Children human subjects review committee. Parental informed consent was obtained, information sheets were provided, and the parents were present during testing.

**Egocenter Measures**

To measure the egocenter, we used a modified Roejlof's method because we have found this method effective and easy to use with children. This method is based on the premise that a rod aligned along the visual axis of one eye appears along the common axis, which passes through the egocenter. A 33-cm rod extended along the child's visual axis from a 1.3-cm high black-and-white fixation target. The nonfixating eye was occluded by a metal shutter (detailed below), and the child's nose was fitted into a groove in the equipment board, directly opposite the fixation point. Beneath the board, but attached to it, was a 26.5-cm lever that pivoted on the same axis as the rod on the upper surface. The children were instructed to maintain fixation, then to hold the lever with both hands and swing it to a position that matched where (on the face) the seen rod was pointing toward them. The position
of the lever was read in millimeters on a scale glued beneath the board. Neither the lever nor the scale was visible to the child (Fig. 1). For each eye, four presurgery and two postsurgery measurements were taken with the rod aligned along the visual axis. After surgery, the treated eye was measured first at the moment the bandage was removed, usually within 4 hours of surgery. The children’s fixation on the specified target and their head position were monitored on each trial to minimize variability in the measured egocenter location.

Roelofs’ method for locating the egocenter, in accordance with Hering’s Laws of Visual Direction, assumes that only one egocenter exists between the two eyes and that an object that stimulates the fovea will be seen on a line passing through the egocenter and the point of intersection of the visual axes. We made three additional assumptions in calculating the location of the egocenter.

One methodological assumption is that the requirement for Roelofs’ method that the intersection of the visual axes be at the fixation point is violated, and therefore the method has a built-in bias. Because the task is monocular and the viewing distance in our study was relatively close, the position of the covered eye was likely to be exophoric, and this would influence the responses. If, for example, the rod on top of the board were aligned with the visual axis of the seeing right eye and the covered left eye were exophoric, the rod would point to the egocenter, but it would also appear slightly angled from the intersection of the visual axes to the egocenter because the common axis would be beyond the target and slightly to the left of it (Figs. 2A, 2B). The children were asked to match what they saw on top of the board by rotating an unseen lever below, which pivoted from the same site as the fixation point. Because the children were seeing the rod at a slight angle along the common axis, we assume they positioned the unseen lever parallel to the orientation of the rod. Because the unseen lever was constrained at the fixation point, positioning it parallel to the rod would result in the lever’s being slightly off the midline toward the seeing eye. There would be two different measurements of egocenter location at the corneal plane, depending on whether the left eye or the right eye were viewing the target. Thus, if a phoria in the covered eye were not controlled, the egocenter measurements would be off the midline toward the viewing eye but by an equal amount for each eye viewing (a bias).

A second methodological assumption is that averaging the measurements of egocenter location, one from each eye viewing the target, eliminates the bias (the phoria is equal in the two eyes). Because only one egocenter location is assumed to exist, this averaging provides a single measure of egocenter location derived consistently across all subjects. Thus, whether the egocenter is in the midline or toward one eye will be revealed when the measurements are signed toward the nonoperated eye.

The third methodological assumption with Roelofs’ method is that the near end of the unseen lever points to the egocenter, and this was the point we measured as the location of the egocenter. The subjects were instructed to fixate a target at the pivot point and to match where, on the face, the seen rod appeared to point.

We have made these assumptions because of our previous work in which we tried measuring the egocenter, in adults, using Roelofs’ method. The subjects were asked to indicate the apparent location of the rod.
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by drawing a line underneath the board with an unseen hand. The results were too variable to be interpreted. We have used Roelof's method with the lever fixed at the pivot point with other normal binocular subjects and found consistent egocenter measurements, over the long-term, to the midline, and with measurements taken with the right eye averaged with those of the left eye.

Eye Position Measurements

We used a photographic technique to measure the amount of phoria or strabismus. It was a fusion-free measure, equivalent to that obtained from the “alternate cover” test for strabismus. If one eye were strabismic and the fellow eye occluded, the strabismic eye would move from the deviated position to fixate the target and the covered fellow eye would make a corresponding movement, following Hering’s Law of Equal Innervation. When the strabismic eye fixated the targets, it was the deviated position of the covered other eye that was measured.

The equipment board (50.4 × 30.5 × 2 cm) was attached to a tripod that could be adjusted to enable the child to sit and comfortably fit the nose into a groove that restricted head movement. The metal shutter/occluder could be made to cover either eye. This shutter was spring operated and, when triggered by the experimenter, instantaneously uncovered the nonfixating eye and activated a power cell that set off the flash and took the picture of both eyes with a Nikon N2000 camera (Nikon, Tokyo, Japan) equipped with a 105 mm Micro-Nikkor lens and 400DX color slide film (Fuji, Mississauga, Ontario, Canada). A Vivitar (Santa Monica, CA) Auto thyristor 550FD flash attachment was also mounted on the surface of the board facing the subject and to the right of the camera, 10 cm from the end of the board. This apparatus is shown in Figure 1. A level was used to ensure that all the equipment was horizontal.

During the calibration procedure, a 40.5-cm ruler stick was fixed to the camera at a distance of 47 cm from the subject’s eyes. The child fixated two targets, white squares with black numbers, set at every 10° mark from 20° left through 20° right. Before surgery, the subject looked at the numbers monocularly, each eye in turn, and both eyes were photographed.

For analysis, the slides were projected onto a screen 150 cm away. The position of the corneal reflection of the flash, relative to the center of the pupil (the first Purkinje image), provided the measure of eye position. The distance between the corneal reflex and the center of the pupil was measured in either a nasal or a temporal direction for each eye in each position in millimeters and then converted to degrees of rotation. The resolution with this system was approximately 2°.

RESULTS

Because not all patients were able to complete the postoperative testing, there were more presurgery measures available for analysis. Four patients with horizontal strabismus did not perform the task after surgery, and two other patients’ (one with horizontal strabismus and one with vertical strabismus) postoperative photographs were not usable (neither could fully open the operated eye), but their postoperative egocenter measurements were used.

Egocenter Measurements

We signed the measurements of egocenter location as negative if they were toward the operated eye and positive if they were toward the nonoperated eye. If, for example, the mean egocenter location of one of the groups was toward the “nonoperated” eye, the results of this method of analysis would show a positive mean egocenter measure off the midline toward the “nonoperated” eye. For the 12 normal children, when the egocenter measurements with the 12 “operation-matched” and the 12 “nonoperation-matched” eyes looking at the target were combined, the egocenter location was 1 mm off the midline toward the nonoperated matched eye (SD = 0.6). For the 12 people with horizontal strabismus, the combined operated and nonoperated eyes’ measure of egocenter location before surgery were at the midline (SD = 0.3). After surgery, for the eight people with horizontal strabismus able to complete the task, the combined operated and nonoperated eyes’ measure of egocenter location was 3 mm (SD = 0.8) off the midline toward the nonoperated eye. For the six people with vertical strabismus, the combined measure of egocenter location before surgery was 4 mm (SD = 0.9) off the midline toward the operated eye, and after surgery it was 4 mm (SD = 0.9) off the midline toward the nonoperated eye. Overall, the egocenter location for the people with normal binocular vision, those with horizontal strabismus (both before and after surgery), and those with vertical strabismus (both before and after surgery) was approximately at the midline.

Before surgery, the egocenter location among the three groups was compared, and no significant differences were found (F [2, 27] = 0.191, P = 0.827). The presurgery egocenter location for the people with strabismus was compared to the postsurgery measure, and no significant differences were found; for the people with horizontal strabismus, t (7) = -0.653, P = 0.535; for the people with vertical strabismus, t (5) = -2.375, P = 0.065.

Eye Position Measures

Eye position measurements of the occluded eye were taken before surgery for the strabismus patients, with
DISCUSSION

We have found that children with strabismus have the same median plane egocenter location as children with normal binocular vision. Furthermore, egocenter location is not affected by strabismus surgery. This makes it unlikely that changes in open-loop pointing responses after strabismus surgery, reported by Steinbach et al., Bock and Kommerell, Gauthier et al., could result from egocenter plasticity. Instead, the changes after strabismus surgery likely reflect either monocular or binocular recalibrations of eye position.

At first glance, our results, collected using Roeffls' method, appear to conflict with Bailey's results. However, Roeffls' method is similar to Bailey's walking experiments for measuring the egocenter in that both are based on Hering's Laws of Visual Direction, and both are monocular tasks. Inherent in any monocular localizing task is the contribution of phoria in the occluded eye, and Bailey noted this as well. Nevertheless, it is likely that Bailey assumed he had measured two egocenter locations, one for each eye viewing, and did not consider that these deviations from the midline were caused by bias. In the people with normal vision, Bailey concluded that their errors in projection (deviations from the midline) were sufficiently small so as to be able to state that they projected from the center of projection (egocenter). However, when we compared Bailey's data between those with normal vision and those with strabismus, there were no significant differences. Thus, the differences become a question of interpretation. Bailey did not average the two measurements of egocenter location, one for each eye, to eliminate the bias and therefore came to a different conclusion.

The eye position, measured from photographs taken while these patients performed the egocenter task and fixated in the primary position, showed that the covered eye of the patients with horizontal strabismus had large deviations (mean = 15.5°) and that those with vertical strabismus and normal children did not have horizontal deviations of any important magnitude. As expected, only the patients with horizontal strabismus showed a large shift in horizontal eye position after the surgery (mean = 14.5°) compared to the patients with vertical strabismus (mean = 2.4°). Thus, the corrective surgery for the horizontal deviations was effective.

In conclusion, children with strabismus have the same egocenter location as children with normal binocular vision, and this is unchanged by surgery. The visual system adjusts to the monocular visual input of the children who have undergone enucleation by shifting the egocenter toward the remaining eye. For people with strabismus who have some input from each eye, the egocenter remains approximately midway between the two eyes. We are left with some unanswered questions about the plasticity of the egocenter. Does the egocenter shift in adults who undergo enucleation much later in life? This could be measured systematically over the long-term by first determining the egocenter location before enucleation and then monitoring its postsurgery stability. Also, preschool children with normal binocular vision have a tendency to sight from the egocenter when they are asked to look through a tube at a target. They tend to place the tube at the bridge of the nose, not over one eye. Would children with strabismus or those who have undergone enucleation do likewise, or would they sight from one eye? The answers to these two questions about egocenter location and plasticity would provide information about a critical period in the development of the egocenter.

Key Words

strabismus, esotropia, exotropia, egocenter location, visual direction

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