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Learning to Look With One Eye: The Use of Head Turn by Normals and Strabismics

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When asked to look through a tube, young children (normal, strabismic, monocularly enucleated) place it between the eyes, while older children turn the head or shut one eye. We videotaped 174 children (normals and strabismics, 2–17 yr of age) and 16 normal adults to find out when and why head turn occurs. In learning to look with one eye, children progressed through a sequence of four responses, categorized by age or amount of head turn. Binocular children use head turn apparently to avoid diplopia, then, most learn to shut one eye. Adults, forced to use the "non-preferred" eye, revert to turning the head. Copyright © 1996 Elsevier Science Ltd.

Head turn Normal Strabismus Cyclopean Monocular

INTRODUCTION

Children have to *learn* to use one eye when faced with tasks that require monocular viewing (e.g., telescope). To adults, it may seem surprising that children do not automatically "know" what to do. Theoretically, however, since people "see" as though from the egocenter (e.g., Hering, 1879/1942; Ono & Mapp, 1995) and have no eye signature¶ (e.g., Helmholtz, 1910/1962; Ono & Barbeito, 1985; Steinbach *et al.*, 1985), the use of one eye has to be learned. When children with normal binocular vision, comitant strabismus, or monocular enucleation (1.8-5 yr of age) were asked to look through a tube at targets, all of the younger children in the *three* groups placed the tube at the bridge of the nose—not over one eye (Barbeito, 1983; Dengis *et al.*, 1993a). Moreover, the normal and strabismic toddlers kept both eyes open. This *Cyclops* effect (Church, 1970) diminished with age, and it was noted (Dengis *et al.*, 1993a) that the older children used two other responses when trying to look with one eye, namely, the turning of the head and the shutting of one eye.

Many older children in the sample turned the head when trying to look through the tube with one eye, while the younger children did not turn the head. For patients with eye movement disorders, head turn serves a purpose: those with incomitant deviations turn the head to achieve some degree of fusion, and those with nystagmus turn the head to the null point in order to maximize visual acuity by damping the nystagmus (von Noorden, 1990). For children with normal binocular vision or comitant strabismus, does head turn also serve to minimize diplopia while they are learning to look with one eye?

Some of the older children shut the non-sighting eye, while the younger children kept both eyes open. The ability to wink voluntarily may not develop until 6–8 yr of age (El-Mallakh *et al.*, 1993), and it has been argued that no one would learn to shut one eye if there were no tasks that forced monocular viewing (Walls, 1951). Perhaps, then, mastering monocular tasks requires a level of motor control and cognitive maturity that comes only with age.

Generally, we wanted to know how children with normal binocular vision or comitant strabismus progressed from the *Cyclops* effect to the response shown by most adults. When adults look through a tube, most place it over the preferred eye, shut the other eye, and do not turn the head. Specifically, we asked the following questions. First, do children progress through a sequence of different responses in the process of learning to look with one eye? Second, is head turn part of this learning process, and age-related? Third, if adults are forced to use the non-preferred eye for monocular tasks, will they revert to using head turn?

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¶To date, there is no evidence that given identical retinal images we can distinguish the impressions of one eye from those of the other. Eye signature is also called eye-of-origin information or utrocular identification (Ono & Barbeito, 1985).

TABLE 1. The number of patients in each of four strabismus types, categorized by surgical history, the mean amount of deviation (*M*), and number of amblyopes per group

Strab	Prev. surg.	Dev'n (diopter)	No surg.	Dev'n (diopter)
ET ($n = 31$)	$n = 16$	$M = 18.4$, SD = 14.3	$n = 15$	$M = 28.4$, SD = 9.5
amblyopes	$n = 11$		$n = 9$	
XT ($n = 20$)	$n = 15$	$M = 19.1$, SD = 8.5	$n = 5$	$M = 20.4$, SD = 11.1
amblyopes	$n = 11$		$n = 1$	
E(T) ($n = 7$)	$n = 3$	$M = 10.0$, SD = 6.5	$n = 4$	$M = 13.0$, SD = 8.3
amblyopes	$n = 0$		$n = 3$	
X(T) ($n = 9$)	$n = 2$	$M = 19.5$	$n = 7$	$M = 22.8$, SD = 9.9
amblyopes	$n = 0$		$n = 1$	

The four types of strabismus are: esotropia (ET), exotropia (XT), intermittent esotropia [E(T)], and intermittent exotropia [X(T)]. Stereopsis ranged from none (-fly) to 40 arc sec, as measured by the Titmus test. Age of onset ranged from infancy to 7 yr. Strab, strabismus; prev. surg., previous surgery; Dev'n, deviation.

METHODS

Observers

The children were tested at The Hospital for Sick Children in Toronto, Canada. The 107 children with normal binocular vision ($M = 7.1$ yr, SD = 3.1) were siblings of patients or patients themselves being treated for non-visual conditions (e.g., tonsillectomies). The 67 children with comitant strabismus ($M = 7.5$ yr, SD = 3.7) were either esotropes or exotropes, none with nystagmus (see Table 1). (Eight other children, five normal and three strabismic patients, refused to complete the task, and their data were not included.) The tenets of the Declaration of Helsinki were followed, the research protocol was vetted by The Hospital for Sick Children human observers review committee, written parental informed consent was obtained, information sheets were provided, and a parent was present during testing. Small toys or movie passes were given to the children. The 16 adult observers ($M = 33.4$ yr, SD = 8.5) with normal binocular vision were students and/or staff at York University, and each was paid $5.00. Degree of stereopsis of all observers was determined by the Titmus test.

Tasks and procedures

The children sat in a tall chair facing the experimenter who was on a lower stool 1 m away (some of the youngest children sat in their mother's lap), and the parents were instructed not to assist the children. Another experimenter videotaped the proceedings using a Sony Video8 camera recorder #LCH-V50. Since forcing attention to detail increases the incidence and amount of head turn (Young, 1988), we asked the children to look through a tube at targets (1 × 1 cm animal stickers) positioned in the midline, 57 cm away from the face. They were also asked to identify a sticker at 5 m. A hat with a measuring tape and thin rod was placed on the child's head (Fig. 2), allowing an estimate of the amount of head turn, with a resolution of about 3 deg. Head turn was measured by the parallax between the tape and the rod.

There were four trials for each of four tube types. A short tube (8.7 cm long, 4.5 cm dia), a long tube (20 cm long, 2.5 cm dia), a cone (26.2 cm long, 3 cm dia at the top, 20.5 cm dia at the bottom), and a kaleidoscope (22.5 cm long, 2.5 cm dia) were used. The tube was held 4–5 cm from the children and moved back and forth across the visual field, and they were made aware they could see through the tube without being aware that this could be a monocular task. They held the tube with both hands in the midline and were instructed to look through it at the target. The children looked through each type of tube once, and the sequence was repeated three times with the tubes presented in random order (16 trials).

The paradigm was the same for adults except that the targets were single black letters (1 cm high) on a white background. In the first condition, the adults were asked alternately to take photos of the letters with a camera, then to look through the long tube at the letters, and this sequence was repeated four times. The eye chosen by each observer as the sighting eye, we termed the "preferred" eye. In the second condition, half the observers had the "preferred" eye patched initially, while the other half had the "non-preferred" eye patched. The adults looked at letters four times through the tube, and then the patch was switched to the other eye and the sequence was repeated.

The videotapes were later reviewed independently by three raters for the children and two raters for the adults. The amount and direction of head turn was recorded, as was the type of response. The response type was determined by where on the face the tube was placed (for example, midway between the eyes or over one eye), and whether one or both eyes were open. We scored the initial placement of the tube for each response.

RESULTS

There was high inter-rater reliability ($r = 0.96$) for the independent raters who reviewed the videotapes and scored the data.

For the normal and strabismic children, the average

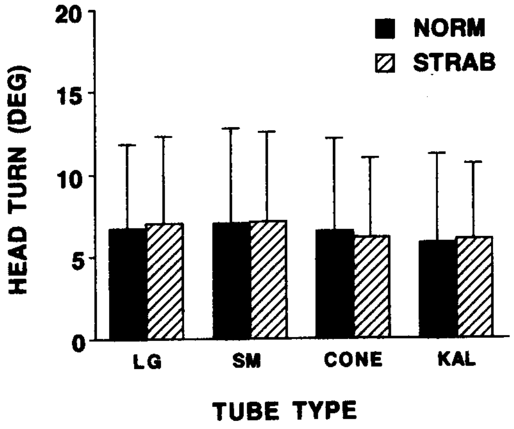


FIGURE 1. Amount of head turn, in degrees, measured for each of four tube types: large tube (LG), small tube (SM), cone (CONE), and kaleidoscope (KAL). There were no differences among the types of tubes for either the normals or the strabismics. Error bars are +1 SD.

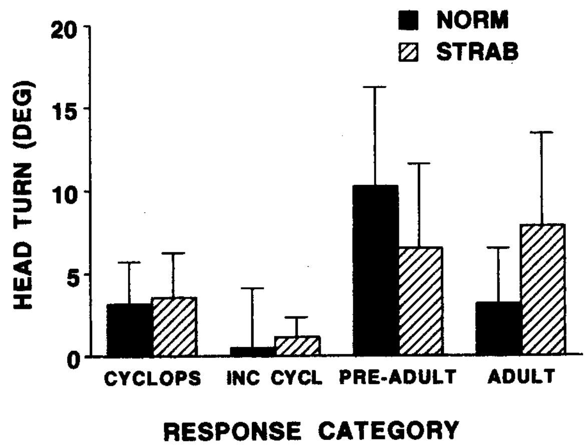
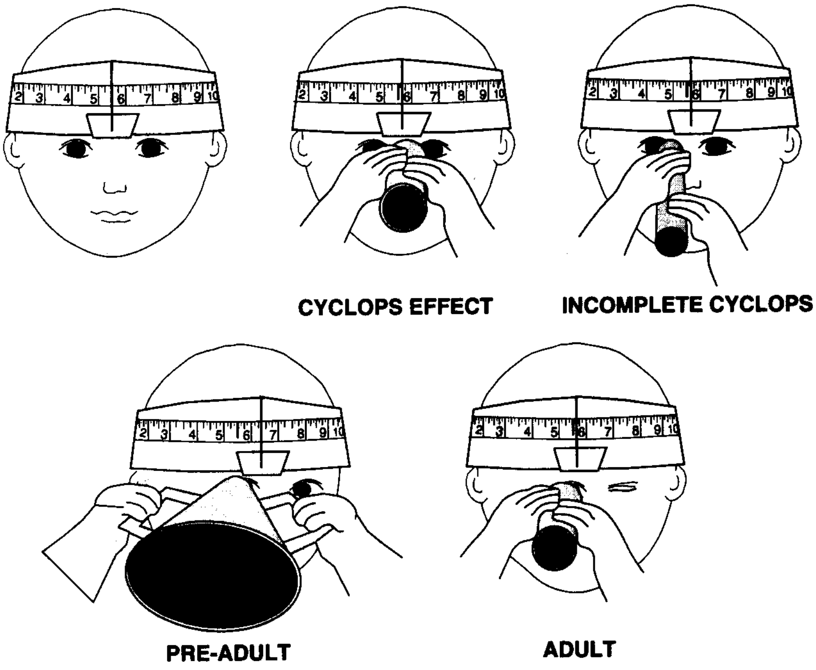


FIGURE 3. Average amount of head turn, in degrees, by response category for the normal and strabismic children. The four categories are: *Cyclops* effect, *Incomplete Cyclops* (INC CYCL), *Pre-Adult*, and *Adult*. Error bars are +1 SD.

amount of head turn demonstrated with each type of tube was calculated. There were no differences in the amount of head turn among the tube types (Fig. 1). Since each observer turned the head approximately the same amount regardless of the type of tube, we collapsed the data across tube type.

Each response fell into one of four response categories (Fig. 2), the sequence of which is as follows. First, there was the *Cyclops* effect, where the tube was positioned at the bridge of the nose. Second, there was an *Incomplete Cyclops* effect, where the tube was positioned slightly off the midline over toward one eye. Third, there was a *Pre-Adult* response, where the tube was placed over one eye while the other eye was kept open. Fourth, there was an *Adult* response, where the tube was placed over one eye while the other eye was shut.

The mean amount of head turn, in degrees, was calculated for the response category demonstrated *most frequently* by each child, with the direction taken into account. (If a head turn brought the eye looking through the tube toward the midline of the body, it was scored as positive; if it moved the eye and the tube away from the



CYCLOPS EFFECT INCOMPLETE CYCLOPS

PRE-ADULT ADULT

FIGURE 2. The four categories of response: the *Cyclops* effect, the *Incomplete Cyclops*, the *Pre-Adult*, and the *Adult*. The children wore a hat with a measuring tape and thin rod, and when they faced straight ahead, the rod was at 5 and a half on the measuring tape.

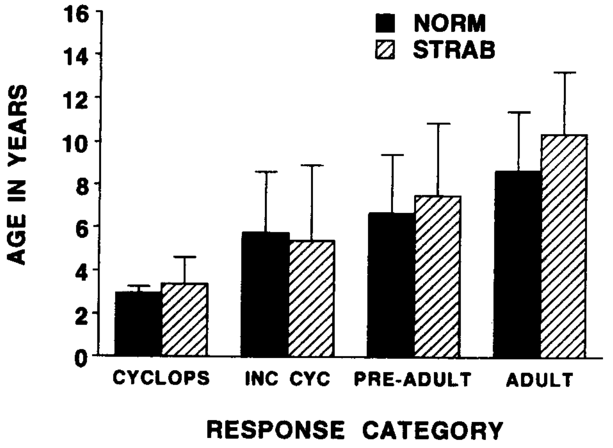


FIGURE 4. Average age of the children demonstrating each response category. Error bars are +1 SD.

midline, it was scored as negative.) These individual means were then averaged across all the children in each group by response category, and compared between the normals and strabismics (Fig. 3).

The mean head turn in the response category shown most frequently was compared in normals and strabismics. Some data were omitted, however. For example, if a child demonstrated 14 *Pre-Adult* responses and two *Adult* responses, we used only the mean amount of head turn for the *Pre-Adult* response. (For two strabismic patients, there were approximately equal numbers of *Cyclops* and *Pre-Adult* responses, as the most frequently demonstrated response categories. We used only the mean of their *Cyclops* responses.) First, there was a significant difference in the amount of head turn demonstrated by the normal children among the four response categories, $F(3,103) = 10.618$, $P < 0.001$. To further determine which responses were significantly different, a Tukey's hsd test was computed. The amount of head turn demonstrated in the *Pre-Adult* response was significantly greater than in each of the other three response categories at the 0.01 level. No significant difference was found between the amount of head turn shown in the *Cyclops* effect, the *Incomplete Cyclops*, or the *Adult* response. Hence, normal children turned the head more when attempting to sight with one eye while both eyes were open. Second, there was also a significant difference in the amount of head turn demonstrated by the strabismics among the four response categories, $F(3,63) = 3.142$, $P < 0.05$. A Tukey's hsd test indicated that there was a significantly greater amount of head turn demonstrated in the *Adult* response than in the *Incomplete Cyclops*, at the 0.05 level. No other differences were significant.

The mean age of the children demonstrating each response category was determined, maintaining statistical independence and collapsed across tube type (Fig. 4). It was the youngest children from both populations who demonstrated the *Cyclops* effect most frequently, χ^2 (3, $n = 174$) = 27.18, $P < 0.001$. The slightly older children demonstrated the *Incomplete Cyclops* response and often turned the head in the negative direction, as though experimenting with the use of head turn.

The older children demonstrated the *Pre-Adult* response. They had learned to place the tube over one eye, and rarely during this response did the children turn the head in the negative direction. This was the response shown most frequently by both the normals (67%) and the strabismics (93%). The normals turned the head significantly more in this response category than that found in the other three categories. Additionally, for the strabismics, there was no correlation between the degree of stereopsis and the amount of head turn in this category ($r = 0.13$).

It was not surprising to find that the oldest children with normal binocular vision or strabismus showed the *Adult* response most frequently, χ^2 (3, $n = 174$) = 18.83, $P < 0.001$. No child with normal vision demonstrated this response before the age of 4 yr and no child with strabismus before the age of 6 yr.

We further analyzed the *Pre-Adult* and *Adult* response categories. First, there were 30 normals ($M = 6.6$ yr, SD = 2.9) who showed the *Pre-Adult* response on all 16 trials, and 19 normals ($M = 9.4$ yr, SD = 3.0) who showed both *Pre-Adult* and *Adult* responses. We compared the amount of head turn between these two subgroups and found a significant difference, $t(47) = -4.821$, $P < 0.001$. Children showing only the *Pre-Adult* response turned the head, on average, 12.6 deg (SD = 5.8), and those showing both responses turned the head, on average, 5.4 deg (SD = 5.6). Presumably with maturity, children began shutting one eye and with this came the knowledge that large head turns were no longer needed even when two eyes were open. Second, 19 strabismics ($M = 8.1$ yr, SD = 3.8) showed the *Pre-Adult* response on the 16 trials and 13 strabismics ($M = 10.4$ yr, SD = 3.7) showed both the *Pre-Adult* and *Adult* responses. There was no significant difference between the amount of head turn shown by the two subgroups, $t(30) = -0.442$, $P > 0.05$. Strabismics showing only the *Pre-Adult* response turned the head, on average, 7.4 deg (SD = 4.9), and those showing both responses turned the head, on average, 6.7 deg (SD = 6.1). Strabismic children used a medium head turn when looking through a tube with one eye, regardless of whether the non-sighting eye were open or shut. Third, normals used a significantly larger head turn than did the strabismics in the *Pre-Adult* response category, $t(92) = -3.413$, $P < 0.01$. Fourth, the normals used a significantly smaller head turn than the strabismics in the *Adult* response category, $t(49) = -3.328$, $P < 0.01$. (All of these strabismics had some degree of stereopsis.) These latter two differences are likely due to decrements in binocularity of the strabismics.

We further analyzed the data of the strabismics. There were no differences between the head turn for near and far fixation, and neither did previous surgery on the horizontal eye muscles affect the amount of head turn. Furthermore, the data of those patients with consecutive esotropia was no different from that of the other strabismics.

The analysis of the adult data is as follows. When looking through a tube, 12 adults demonstrated the *Adult* response, three adults showed the *Pre-Adult* response, and one observer initially showed the *Cyclops* effect, then slid the tube over to cover one eye and shut the other eye. All of the head turn responses on every trial were in the positive direction. The adults showed a significantly greater amount of head turn when looking through the camera viewfinder than when looking through the tube, $t(15) = 4.003$, $P < 0.01$. They turned the head, presumably, to avoid hitting the nose with the camera. This suggests that adults used different responses depending upon the nature of the monocular task. Furthermore, they showed a significantly larger head turn when looking through the tube with the "preferred" eye patched compared to when the "non-preferred" eye was patched, $t(15) = -2.702$, $P < 0.01$.

DISCUSSION

This study confirms that children have to *learn* to use one eye in order to perform monocular tasks, and this learning occurs in a sequence of four responses that are defined by age or amount of head turn. First, the *Cyclops* effect, in which children ($M = 3.2$ yr of age) place the tube approximately at the midline of the head and keep both eyes open. Second, the *Incomplete Cyclops* response, in which children ($M = 5.6$ yr of age) place the tube over toward one eye and keep both eyes open. Third, the *Pre-Adult* response, in which children ($M = 7.1$ yr of age) place the tube over one eye, keep both eyes open, and turn the head. Fourth, the *Adult* response, in which children ($M = 9.5$ yr of age) place the tube over one eye and shut the other eye. In short, as children mature, they progress from the *Cyclops* effect to the *Adult* response by learning, first, to place the tube over one eye, second, to turn the head, and finally, to shut the non-sighting eye.

Many of the younger children in this study turn the head when looking through a tube with one eye while both eyes are open (*Pre-Adult* response). There are two reasons for this. First, we think that normal children turn the head in order to minimize diplopia because they do not yet know how to shut one eye. Consistent with this hypothesis, the strabismic children use a significantly smaller head turn, presumably, because they suppress the second image (von Noorden, 1990). Second, we think that children also turn the head in order to avoid hitting the nose (i.e., the nose would get bumped if they did not turn the head when looking through a keyhole or a camera's viewfinder). Younger children, however, have not yet learned to differentiate among monocular tasks the way adults have, and therefore the children turn the head regardless of the type of monocular task. For example, younger children turn the head unnecessarily when looking through the kaleidoscope.

Many of the older normal children no longer turn the head when looking through a tube with one eye and the other eye is shut (*Adult* response). Contrary to this, the older strabismic children with some stereopsis continue to turn the head, perhaps because the absence of diplopia does not register as strongly in these children as it does in the normals. Consistent with this hypothesis, when normal children begin to shut the non-sighting eye, they stop turning the head even when they revert to keeping two eyes open. The strabismic children, however, do not alter the amount of head turn under the same circumstances. This fact raises a question. Would adult strabismics with some stereopsis continue to turn the head when looking through a tube (e.g., a telescope) with one eye while shutting the non-sighting eye?

Although the necessity of closing one eye apparently arises because of diplopia, the ability to use just one eye for certain tasks also requires a level of motor control and cognitive maturity that comes only with age. Hence, many children eventually learn to shut the non-sighting eye. We find that some children with normal binocular vision can voluntarily shut one eye by 4 yr of age, contrary to what is implied by the report that this ability may not develop before the age of 6–8 yr (El-Mallakh *et al.*, 1993). (The variability in the ages was not provided in this report.) We know that strabismics have this ability as well, although none of the strabismic children with some stereopsis learned to shut the nonsighting eye before the age of 6 yr.

Most adults with normal binocular vision consistently shut the same eye for monocular tasks and do not turn the head. These same adults revert to turning the head when forced to sight monocularly with the eye that they usually shut. This fact raises two further questions. With practice, would normal adults stop turning the head and learn to shut the eyelid of the "preferred" eye with ease? Does the preference for sighting with one eye develop because it is easier to shut the eyelid of the "non-preferred" eye?

In sum, children with normal binocular vision or comitant strabismus have to overcome the consequences of having an egocenter located approximately at the midline of the head (Roelofs, 1959; Dengis *et al.*, 1993b). The information from the two eyes is integrated and children locate objects from the egocenter (Ono, 1991). Hence, they do not automatically know to use one eye for certain tasks. Children deal with the world using two eyes before they learn to use one eye.

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