Stability of human binocular alignment in the dark and under conditions of nonfixation

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PURPOSE To evaluate the stability of human binocular alignment under conditions of altered fixation and luminance.

METHODS Horizontal binocular alignment in 8 healthy orthotropic subjects was measured using infrared video-oculography (VOG) under conditions of binocular fixation and luminance change. Each testing condition was preceded by a binocular fixation period in room light (475 lux) to define the baseline binocular alignment. Binocular alignment was then measured in darkness without fixation, in room light through a semitranslucent filter that precluded fixation, and in darkness with a distant fixational target. We used the signed rank test to determine statistically whether these experimental conditions induced significant binocular alignment change from each baseline binocular alignment.

RESULTS The mean horizontal binocular alignment in the dark without fixation was similar to baseline binocular alignment ($0.2° \pm 2.8°$; $P = 0.4$). The mean horizontal binocular alignment without fixation in room light was also similar to baseline binocular alignment ($-1.4° \pm 1.6°$; $P = 0.08$). The mean horizontal binocular alignment in the dark when a fixational target was provided showed an exodrift compared to baseline alignment ($2.3° \pm 1.0°$; $P = 0.0004$).

CONCLUSIONS The human brain does not require visual input to maintain binocular alignment on a short-term basis. The resilience of binocular alignment probably reflects the presence of phoria adaptation. (J AAPOS 2016;20:353-357)

Patients undergoing strabismus surgery are told that binocular alignment is an active process, wherein the brain requires simultaneous visual input from both eyes to hold the eyes straight. We assume that sensorimotor fusion is both necessary and sufficient for this process to occur. But is this correct? If so, then binocular misalignment should develop in the dark or in the absence of any fixational or peripheral stimulus. The natural anatomical position of the orbits would predict an exodeviated position of rest for the eyes under these conditions.[1,2] Even in nonstrabismic individuals, the eyes are mildly exodeviated during nondepolarizing paralyzing anesthesia, a condition that suspends innervation to the extraocular muscles. We often assume that fusional convergence actively overcomes this exodeviated position to maintain robust binocular alignment in the awake state, yet the degree of exophoria exhibited by most individuals does not approximate the baseline anatomical position of the orbits or the resting position of the eyes under deep general anesthesia.[3] Other factors must be at play.

In 1940 Bielschowsky[4] observed that "a so-called compensating innervation of the eyes maintained by the fusion apparatus does not disappear immediately after fusion is broken, but decreases very slowly, and that not always without a temporary recurrence of a fraction of the fusion innervation…. and that during temporary suspension of binocular vision, only a fraction of the heterophoria will become manifest." In 1958 Walter Lancaster[2] posed the following diagnostic question: "What will happen when, in addition to the cover over one eye, the other eye is covered also. This will abolish the fixation reflex. When it is abolished, what forces will continue to act? It is often stated that when the fusion reflex is eliminated, the eyes assume the position of rest. How much more would it be true if the eyes would assume the position of rest if both fusion and fixation were eliminated?" If fusional convergence alone is used to maintain the baseline horizontal alignment of the eyes then the eyes should revert to an exodeviated position in total darkness. To further examine the role of simultaneous binocular visual input in maintaining binocular alignment, we utilized video-oculography (VOG) to define the relative effects of total darkness in both eyes and binocular absence of fixation on binocular alignment in normal individuals.

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Table 1. Video-oculography testing protocol

Step	Timing	Process
1	00:00	Fixation in normal light for 15 sec (white background, black cross as fixation target)
2	00:15	Mask OU for 2 minutes
3	02:15	Fixation in normal light for 15 sec
4	02:30	Opaque filter OU for 30 sec
5	03:00	Opaque filter + occlusion OS 15 sec
6	03:15	Opaque filter + occlusion OD 15 sec
7	03:30	Opaque filter + flashlight OS 15 sec
8	03:45	Opaque filter + flashlight OD 15 sec
9	04:00	Opaque filter + flashlight OU 30 sec
10	04:30	Fixation in normal light for 15 sec
11	04:45	Fixation in darkness (all lights off, black background/red cross) for 30 sec
12	05:15	Fixation in darkness + occlusion OS for 15 sec
13	05:30	Fixation in darkness + occlusion OD for 15 sec
14	05:45	Fixation in normal light for 15 sec
15	06:00	Fixation in bright light (normal light + bright ceiling lights on, white background, black cross as fixation target) for 30 sec
16	06:30	Occlusion OS, fixation OD (bright light) 15 sec
17	06:45	Occlusion ODfixation OS (bright light) 15 sec
18	07:00	Fixation in normal light for 15 sec
19	07:15	Occlusion OS fixation OD for 15 sec
20	07:30	Occlusion OD fixation OS for 15 sec
21	07:45	Fixation OD, flashlight OS 15 sec
22	08:00	Fixation OS, flashlight OD 15 sec
23	08:15	Fixation in normal light for 15 sec

OD, right eye; *OS*, left eye.

Methods

This study was approved by the Mayo Clinic Institutional Review Board and written informed consent was obtained for the testing of all subjects. All testing was conducted in a manner compliant with the US Health Insurance Portability and Accountability Act of 1996.

Eight healthy nonstrabismic subjects (median age, 33 years; range, 11-57; 6 females) were included. Exclusion criteria included inability to perform VOG protocol (age younger than 8 years), a phoria $>8^{\Delta}$, a refractive error >3 D (unless corrected with contact lenses), or a known global developmental or neurological abnormality.

Simultaneous movement of both eyes was recorded using the enso-motoric infrared video-oculography system (SMI 3D-VOG; SensoMotoric Instruments, Teltow, Germany). Infrared video cameras in a head-mounted mask allow 3-dimensional eye movement recording in complete darkness.[5] VOG positional recordings at 60 Hz (60 frames per second) were analyzed. The sequence of stimulus conditions for our video-oculography protocol is summarized in Table 1. The fixation target was presented as a black cross bar against a white screen at 3 m with normal room light and a red cross against a black background with the light off for the dark condition.

Each testing condition was preceded by a binocular fixation period in normal room light (475 lux) for 15 seconds to establish baseline position for both eyes. Binocular alignment was tested under the following three conditions: (1) without fixation in the dark, with the VOG mask completely occluded with a black cover for 2 minutes; (2) without fixation in room light, with a translucent filter that eliminated the fixation target placed before both eyes for 30 seconds in the normal room light and patients then instructed to stare straight ahead through the filter; and (3) with fixation in the dark, with the subject allowed to fixate on a distant projected red light cross in a dark room for 30 seconds.

The last 5 seconds (300 frames) of the position of each eye for baseline and the three experimental conditions was used, because ocular alignment stabilized 5-10 seconds after disruption of binocular vision was made.[6] To reduce “noise” from the data, we removed all the values that corresponded to a loss of signal from the machine (assigned zero by the VOG software) and all values that exceeded a 30° movement, which most likely represented a blink artifact or fixation loss.[7]

We calculated the 50th percentile of the remaining values of the horizontal recordings, during each the last 5-second segments and used these values to represent the horizontal position of each eye and to calculate the relative binocular alignment change from each baseline to each testing condition, as follows:

$$(\text{Left}_{\text{baseline}} - \text{Left}_{\text{condition}}) - (\text{Right}_{\text{baseline}} - \text{Right}_{\text{condition}})$$

Relative binocular alignment change for each condition was derived, yielding mean values for each subject under each condition. We also calculated 95% confidence intervals of the mean difference to represent a reasonable range of values that our data represent. The signed rank test was used to determined whether these values were statically different from 0. If they were, we concluded that experimental testing condition had induced a horizontal alignment change of the eye.

Results

The clinical results are summarized in Table 2. Five subjects were orthophoric, whereas 3 had a negligible