Is Listing's law preserved in the vertical fusional reflex?

Dominik Straumann, Eveline Müller
from the Neurology Department, University Hospital, Zürich, Switzerland

Introduction

When a vertical prism is inserted before one eye during binocular viewing, there is intorsion of the eye that makes a corrective downward movement and extorsion of the eye that moves upward (Enright 1992). This small effect (about 1 deg) was found by optical methods in normal subjects with gaze straight ahead. The additional finding of a translatory displacement in the nasal direction, which was observed in the downward-correcting eye, led to the conjecture that the torsional component during vertical fusion is predominantly produced by the superior oblique muscle. We asked whether such changes in eye torsion were independent of eye position, i.e. whether the same torsional displacement could also be observed in all secondary and tertiary eye positions. In this case the plane of eye rotation vectors (*Listing's plane*) (Helmholtz 1867) would show a parallel shift along the torsional axis during vertical fusion. Other possibilities include a tilt of Listing's plane, implying a linear relation between the direction of gaze and torsional eye position change, or even a violation of Listing's law if three-dimensional eye positions no longer lie in a plane.

Methods

Three-dimensional eye positions were recorded in three healthy subjects using dual search coils (Robinson 1963). A tangent screen was located 164 cm in front of the measured right eye. In the first set of trials, subjects had to wear glasses with a 0.75 dpt base-up prism before the right and a 0.75 dpt base-down prism before the left eye. During binocular viewing this configuration produces a corrective downward movement of the right eye and an upward movement of the left eye to prevent vertical double-vision. In a second set of trials, experiments were repeated for control without glasses. One experiment consisted of 6 trials with the following sequence: (1) Calibration task of the right eye with the left eye covered. (2) 30 seconds of spontaneous eye movements with the subject looking at the screen with the left eye still covered. (3) Repeating 2, but with binocular viewing. Off-line, rotation vectors (Haustein 1989)[1] were computed for all sample points using the respective calibration values. Two planes were fitted to the three-dimensional data points: one plane for monocular viewing data and one plane for binocular viewing data. Orientation of both planes were described by their rotation from a frontal plane (y-slope and z-slope) and their shift along the torsional axis (x-offset)[2]. The standard deviation (x-stdev) of all data points from the fitted planes gave a measure how well Listing's law was observed (Fig. 1). For further analysis, we considered the differences of all parameters between monocular and binocular viewing.

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[1] Rotation vectors describe three-dimensional eye positions as virtual rotations from the reference position. The orientation of a rotation vector is given by the orientation of the rotation axis and its length by $\tan(\rho/2)$, where ρ is the angle of rotation.

[2] The x-axis (torsional axis) points forward, the y-axis (horizontal axis) leftward, and the z-axis (vertical axis) upward. Axes are perpendicular and head-fixed. Signs of rotations follow the right-hand rule.

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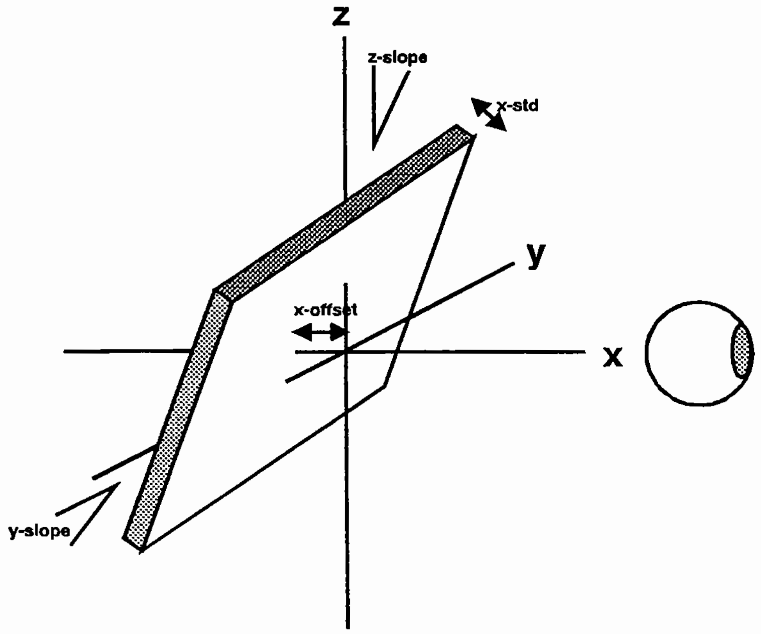
Figure 1: *Parameters describing the orientation of a Listing plane (side view of the eye)*



Results

Fig. 2A shows differences of the z-slope between monocular and binocular viewing in the three tested subjects (A, B, C). Open squares denote differences in the control trials, i.e. without glasses (6 trials), and filled circles denote differences with the subjects wearing vertical prisms (6 trials). There is no clear tendency of a plane rotation about the horizontal axis during vertical fusion. Fig. 2B indicates that in all three subjects there is some tendency for an inward rotation of the Listing plane during vertical fusion. There was no significant shift of the measured Listing planes along the torsional axis (Fig. 2C). The deviations of eye positions from a best-fit plane did not change between monocular and binocular viewing, independent whether subjects used vertical-prisms or not (Fig. 2D).

Figure 2A: *Z-slope differences*

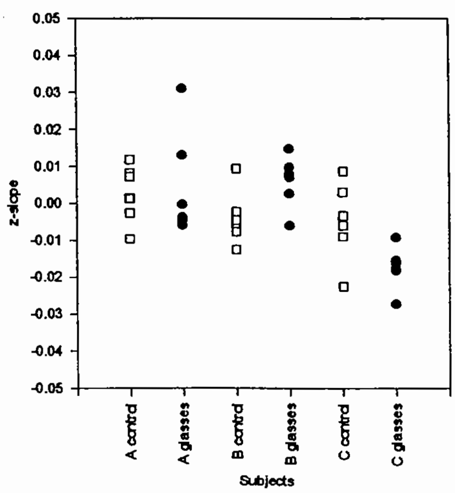


Figure 2B: *Y-slope differences*

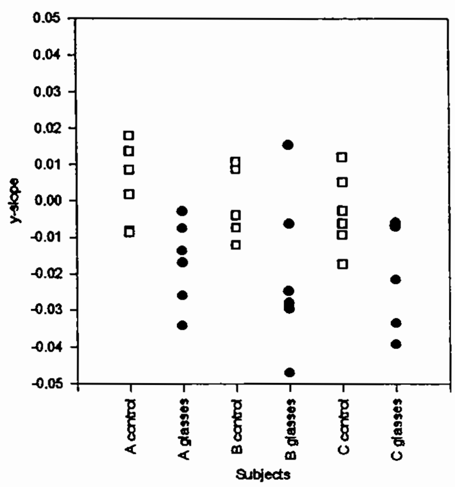


Figure 2C: *X-offset differences*

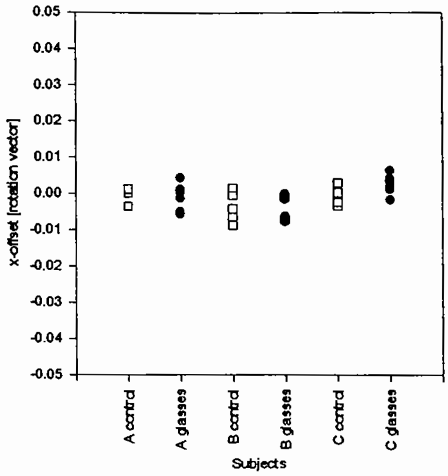
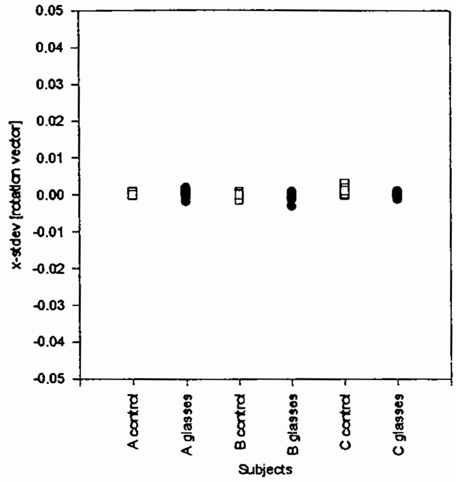


Figure 2D: *X-stdev differences*



Conclusions

In three normal subjects, Listing's law was preserved in the vertical fusional reflex, i.e. there was no significant increase in standard deviation of three-dimensional eye positions from a best-fit plane. On average, the Listing plane of the eye, which made the downward correction, rotated inward about the head-vertical axis by around 1 deg. There was no significant torsional offset of the planes during vertical fusion.

These data suggest that the vertical fusional reflex consists not just of simple activity changes of the vertical recti and superior oblique eye muscles but of more complex modifications of eye muscle synergy, needed to maintain Listing's law. As during vergence (Mok et al. 1992), eye rotation vectors during vertical fusion are still restricted to a Listing plane, but the orientation of the plane is modified. The functional consequences of these findings are yet unclear.

Acknowledgment

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References

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