Influence of Orientation of Exiting Wire of Search Coil Annulus on Torsion after Saccades

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Purpose. Research has shown that the orientation of the exiting wire from a scleral search coil (nasal in the original coil, inferior in the modified coil) influences the pattern of torsion associated with blinks, presumably due to the upper eyelid touching the wire. The present study was conducted to investigate whether coil wire orientation also influences the pattern of torsion during fixation after saccades and consequently influences parameters that determine Listing's plane and Donders' law.

Methods. Three-axis, binocular eye rotations were recorded in three healthy human subjects looking at an array of small light-emitting diodes at a 124-cm distance. They made predominantly vertical or predominantly horizontal saccades (5–40°, amplitude) at three (0 ± 20°) azimuths, or elevations.

Results. With the modified coil, the horizontal component of Listing's primary position was similar for horizontal (mean temporal deviation, 2.9°) and vertical (3.3°) saccades. With the original coil, the horizontal component of primary position was more temporal after horizontal (12.3°) than vertical (6.1°) saccades. The vertical component of primary position was similar with both coils after horizontal and vertical saccades. Listing's plane was thinner with the modified coil after horizontal (standard deviation of torsion from a plane of 0.71° vs. 1.31°) and vertical (0.84° vs.1.67°) saccades. The standard deviation of torsion at a given eye position (Donders' law) was smaller with the modified coil.

Conclusions. Measures of torsion after horizontal or vertical saccades depend on whether the coil wire exits nasally or inferiorly and, with the original coil, whether the saccades are horizontal or vertical. Lid contact may account for these potential artifacts. They must be appreciated in the interpretation of three-dimensional search coil recordings, using the scleral annulus. (*Invest Ophthalmol Vis Sci.* 2004;45:131–137) DOI: 10.1167/iovs.03-0615

A previous study has shown that the orientation of the exiting wire of scleral search coils influences the pattern of torsion associated with blinks.[1] Compared with the commercially available original dual search coil, which was oriented with the wire exiting nasally, the modified coil, with the wire lead exiting inferiorly on the inner rim at 6 o'clock (see Fig. 1) showed a different pattern of torsional eye movements during blinks: First, the initial torsional movement was monophasic when measured with the modified coil and biphasic with the original coil. The difference was presumably due to the upper eyelid's touching the wire when it was exiting nasally and thus rotating the annulus. Second, the scatter of torsional eye positions was less after blinks, when measured with the modified coil compared with the original coil. Measures of eye positions in this study, however, were restricted to straight-ahead gaze only.

In this study, we investigated whether the orientation of the coil wire also influences the pattern of torsion during and after saccades and consequently influences the parameters that define Listing's plane. We asked whether the thickness and the orientation of Listing's plane (determined with fixations in 0 ± 20° field of gaze) depends on the orientation of the exiting wire (nasal in the original, inferior in the modified coil). We recorded simultaneously binocular three-dimensional eye movements during vertical and horizontal saccades in three healthy human subjects and compared the two different search coils.

Methods

Subjects

Three healthy men (ages: 31, 34, and 57 years) gave consent and participated in the study after being informed of the experimental procedures. Visual acuity of each eye was 20/20, and the three subjects had no neurologic or ocular motor disorder. Protocols adhered to the Declaration of Helsinki for research involving human subjects (adopted by the 18th World Medical Assembly, Helsinki, Finland, in 1964; revised last in 2000) and were approved by the local ethics committee (institutional review board [IRB]).

Experimental Setup

The movements of each eye were recorded using dual (three-axis) search coils (manufactured by Skalar, Delft, The Netherlands). We tested with both the commercially sold, original version of the scleral search coil and a modified version with the wire exiting inferiorly that has been described previously.[1] The field coil is a modified Remmel system[2] consisting of a cubic coil frame of welded aluminum with a side length of 1.02 m, which produces three orthogonal magnetic fields with frequencies of 55.5 (horizontal), 83.3 (vertical), and 41.6 (frontal) kHz, and intensities of 0.088 Gauss. Additional details about processing of the analogue data and the calibration of the search coil system have been described elsewhere.[3]

Experiments

Subjects sat inside the coil frame so that the center of the interpupillary line coincided with the center of the frame. During eye movement recordings, the head of the subject was immobilized with a bite bar. With an inclinometer, we defined the position of the head by the earth-horizontal orientation of the bite bar. After the surface of the eye was anesthetized with proparacaine HCl 0.5% (Ophthetic, Allergan, Irvine, CA), dual search coils were mounted on both eyes. In otherwise

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Supported by the Roche Research Foundation (Basel, Switzerland), the Swiss National Science Foundation Grant 32-51938.97 SCORE A/31-63465.00; the Betty and David Koetser Foundation for Brain Research, Zurich, Switzerland; The Robert and Annetta Coffelt Fund; and National Eye Institute Grant EY01849.

Submitted for publication June 18, 2003; revised September 16, 2003; accepted September 22, 2003.

Disclosure: **O. Bergamin**, None; **S. Ramat**, None; **D. Straumann**, None; **D.S. Zee**, None

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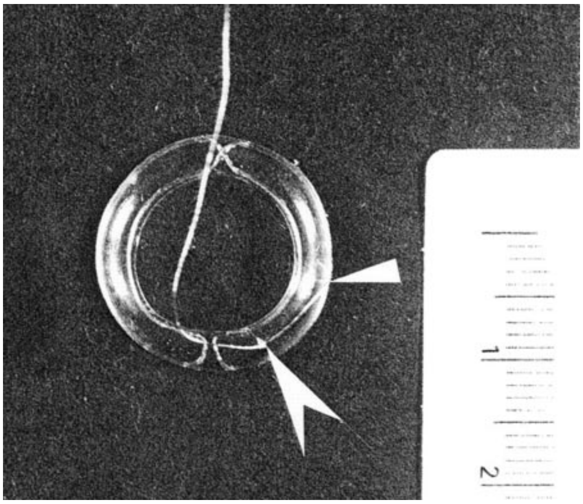

FIGURE 1. Photograph of search coil. The original search coil was modified so that the wire leads left the inner border of the search coil annulus at 6 o'clock. *Arrowhead*: first stitch that gives the initial direction (clockwise for a right eye coil, and counterclockwise for a left eye search coil). *Two-tailed arrowhead*: second stitch that gives the wire the correct direction when leaving on the top of the annulus. The ruler indicates centimeters. Adapted with permission from Bergamin O, Bizzarri S, Straumann D. Ocular torsion during voluntary blinks in humans. *Invest Ophthalmol Vis Sci*. 2002;43:3438–3443.

complete darkness, subjects were asked to fix on light-emitting diodes (LEDs) at different locations on a tangent screen (distance, 124 cm), which were switched on and off every 2 seconds, so that only one LED was lit at any time.

Each of the three subjects participated in four sessions on different days as follows: (1) modified coil in the right eye, original coil in the left eye; (2) original coil in the right eye, modified coil in the left eye; (3) original coils in both eyes; and (4) modified coils in both eyes.

In each session, subjects were tested with the following paradigms, always with both eyes viewing:

1. Ten repetitions each of horizontal saccades of 5°, 10°, 20°, and 40° amplitude at 20° elevation, 20° depression, and then at straight-ahead gaze. Figure 1 shows four repetitions of this paradigm with the original coil in the left eye and the modified coil in the right eye.
2. Ten repetitions each of vertical saccades of 5°, 10°, 20°, and 40° amplitude at 20° right gaze, 20° left gaze, and then at straight-ahead gaze.

Data Analysis

The data were analyzed off-line (MatLab, ver. 5.3; The MathWorks, Inc., Natick, MA). Details of the analysis are described elsewhere.[3] Eye positions were expressed in rotation vectors. A rotation vector is oriented parallel to the axis of rotation that moves the eye from the reference position to the current position. The length of a rotation vector is given by $r = \tan(f/2)$, where f is the amount of rotation. For the convenience of the reader, the three components of rotation vectors are given in degrees. Because rotation vectors obey the right-hand rule, the signs of the horizontal and vertical components had to be inverted to make them consistent with the clinical definition of directions. Thus, in the following experiments, the rightward, upward, and clockwise rotations of the ocular globe, as seen by the subject, are positive.

For the analysis of static torsion before and after saccades we used eye positions immediately before and 800 ms after the onset of the saccade. Individual saccade trials were manually selected before inclusion for data analysis. Those trials were excluded that contained an obvious slip of the annulus on the eye or a blink artifact or those in which the subject made a very slow saccade or two saccades instead of one. Over all subjects and all trials, the number of saccades that were included ranged from 25% to 94% of trials, with a mean of 58%. Because individual data sets had 510 trials, there were ample data points covering all positions across the visual field. This sufficiency of the amount of data was verified further after the unusable trials were excluded. There was no statistically significant difference in the number of saccades included for further analysis comparing the two types of coils.

Listing's Plane and Primary Position: Helmholtz Definition

Listing's law describes the mathematical relation between the horizontal and vertical direction of the line of sight and the simultaneous ocular torsion. Its defined as the best planar fit through the three-dimensional (x = torsional, y = vertical, and z = horizontal) data of ocular position:

$$x = a_0 + a_1 \cdot y + a_2 \cdot z$$

The primary position represents the unique reference position from which horizontal and vertical ocular positions can be reached without a rotation of the eye about its line of sight. The primary position vector is normal to Listing's plane if primary position coincides with the reference position. If Listing's plane does not lie parallel to the frontal plane of the head, primary eye position is displaced from the straight-ahead position in the direction of the tilt of Listing's plane. The horizontal (p_h) and vertical (p_v) components of primary position were computed from the slopes of the regression coefficients of the Listing's plane and are expressed in degrees[4]:

$$p_h = 2 \cdot a_1 \cdot \frac{180}{\pi}, \quad p_v = -2 \cdot a_2 \cdot \frac{180}{\pi}.$$

For analysis of the curvature of the plane, a twist factor was computed from a second-order fit to the data points.[5]

Donders' Law

For analysis of Donders' law (the torsional orientation of the eye that is fixed for any given horizontal and vertical eye position) we measured the standard deviation of torsion during fixation at various positions of gaze across the field of gaze.

RESULTS

Figure 2 (subject S1) shows a representative example of the torsional component of eye rotation (dark traces) with the original (Fig. 2A) and the modified (Fig. 2C) coil during the first four repetitions of the horizontal saccade paradigm (paradigm 1, see the Methods section). In the left eye (Fig 2A; original coil) the torsional component varied slightly with the 20° up and the 20° down gaze of this eye (note the undulation of the torsional trace over time), but not so in the right eye (Fig 2C; modified coil). Both coils, however, showed a small clockwise (CW) rotation with right gaze and a small counterclockwise (CCW) rotation with left gaze (Figs 2B, original coil, and 2D, modified coil). The open arrows indicate that sometimes there were changes in dynamic torsion during and just at the end of saccades. This intra- and immediately post-saccadic "blip" torsion could be greater (e.g., Fig 2B, top open arrow; 2D, bottom open arrow) or less (e.g., Fig 2B, bottom open arrow, or Fig 2D, top open arrow) than that expected from any change in static torsion associated with the change in eye position from the saccade itself. The blip torsion promptly decayed to a steady value at fixation.

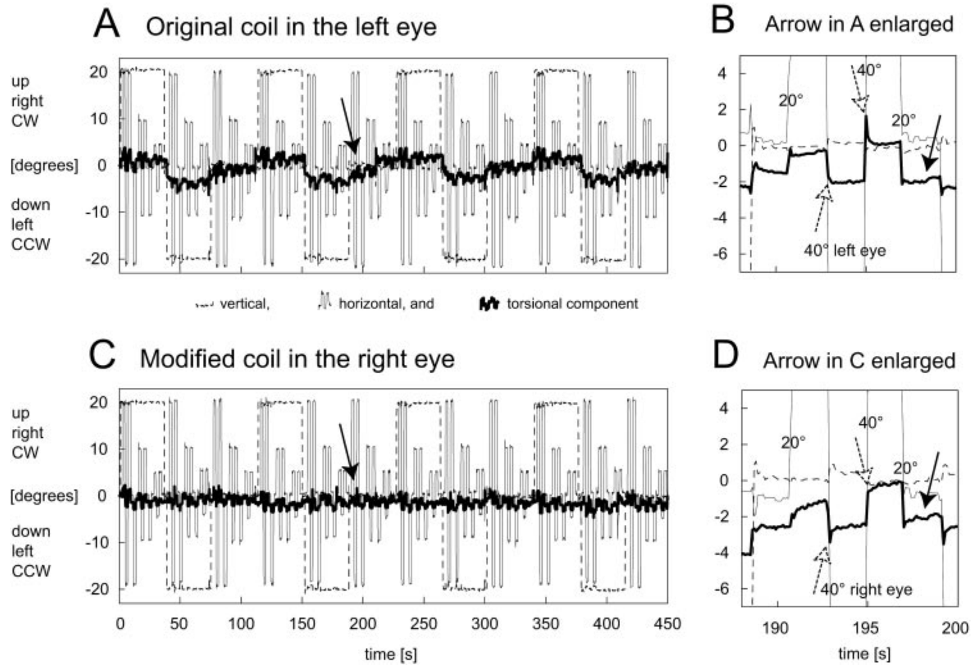

FIGURE 2. Horizontal saccades of different sizes (5°, 10°, 20°, 40°) at three different elevations (−20°, 0°, 20°). Traces of horizontal (*thin sold lines*), vertical (*thin dashed lines*) and torsional (*thick solid lines*) components of eye movements are shown with the original coil in the left eye (**A**) and the modified coil in the right eye (**C**). The torsional component varied more with the vertical component in the eye with the original coil than with the modified coil. The magnified traces of the torsional eye rotation during horizontal saccades made along the vertical midline (**A**, **C**, *arrows*) are shown in (**B**) and (**D**). They sometimes show a relative change in torsion during or just at the end of saccades) that is independent of the type of search coil (**B**, **D**, *open arrows*, blips). *Filled arrows*: static torsion values. CW: clockwise; CCW: counterclockwise rotation.

To characterize the orientation of Listing's plane for each eye in each paradigm, we calculated primary position. The amount by which primary position differed from the reference (straight ahead) position is reflected in the changes in torsion that are associated with different vertical and horizontal eye positions. Figure 3 summarizes the primary positions of both eyes based on fixations immediately preceding vertical and horizontal saccades in all three subjects, using the original and the modified coils. The amount by which Listing's plane was rotated temporally varied considerably in the four conditions. With the modified coil, Listing's primary position was similar for horizontal saccades (mean temporal distance from zero: 2.9°, Fig. 3A) and vertical (3.3°, Fig. 3C) saccades. With the original coil, primary position was more temporal after horizontal (12.3°, Fig. 3B) than after vertical (6.1°, Fig. 3D) saccades. Vertical primary position, however, was similarly located with both coils (modified: 16.6°, Fig. 3A and 11.5°, Fig. 3C; original: 14.2°, Fig. 3B and 8.41°, Fig. 3D). The intersession difference of primary position was lower with the modified coil than the original coil, as depicted with the line lengths on top of the location of primary position. Most of the difference occurred with the original coils during horizontal saccades (see longest line between the two sessions in Fig. 3B), with the next largest difference being with original coils during vertical saccades. When using the modified coils, there were smaller differences in primary position between the two sessions.

We next asked how well our data could be fit to a single plane in each testing condition. The thickness of Listing's plane, as reflected in the standard deviation of torsion from the plane, was calculated at each session separately and then summarized for all six eyes after the average was calculated from the two repetitions (Fig. 4). Listing's plane was thinner with the modified coil after both horizontal (standard deviation of torsion from plane of 0.71° vs. 1.31°; $P = 0.002$) and vertical (0.84° vs. 1.67°; $P = 0.02$) saccades. We also asked whether there was any curvature of the plane using the "twist" factor. There was no statistically significant difference between the two types of coil with either horizontal or vertical saccades, but the curvature of Listing's plane was significantly greater with vertical than horizontal saccades with either type of coil (modified coil: 0.38 vs. 0.20; $P = 0.014$; original coil: 0.48 vs.

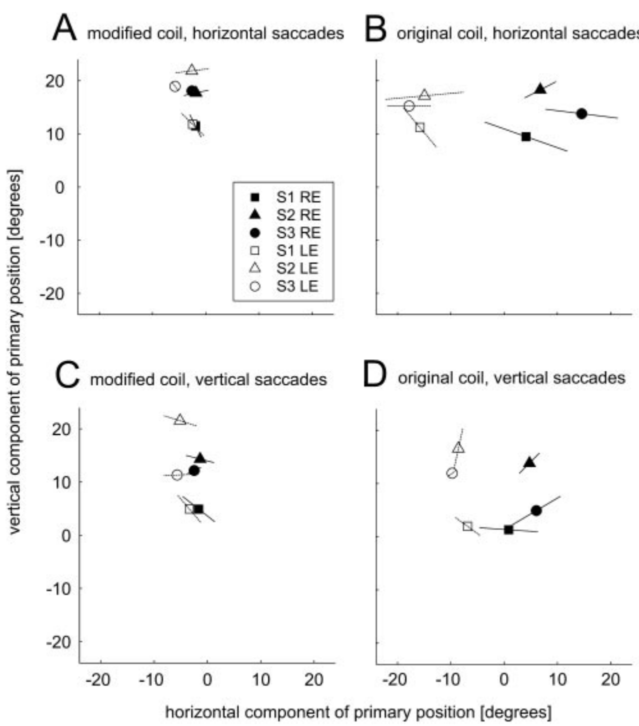

FIGURE 3. Location of primary position (as defined by Helmholtz) of the right eye (RE, *filled symbols*) and left eye (LE, *open symbols*) of the three subjects. The horizontal component of the primary position differed, depending on whether the saccades were vertical or horizontal with the original coil (**B** versus **D**) but not with the modified coil (**A** versus **C**). Using the original coil, the temporal rotation of primary position was more with horizontal saccades (**B**) than with vertical saccades (**D**). The lines connect the values of primary position measured in each of the two session; the data points represent the average of the two.

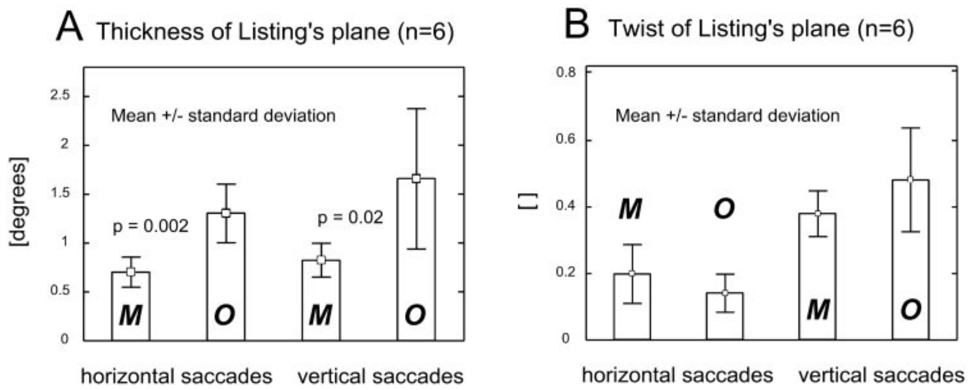

FIGURE 4. (**A**) The thickness of Listing's plane calculated for each session and then averaged for all subjects was significantly lower with the modified coil (*M*) than with the original coil (*O*) for both vertical and horizontal saccades. The height of the bar represents the SD of the six measurements. (**B**) The twist factor was greater with vertical than horizontal saccades, independent of the type of coil.

0.14; $P = 0.001$, see Fig. 4B). The twist factor was always positive, indicating that the fitted surface showed the same type of curvature, not the inverse shape.

Next, Donders' law was investigated from the same data set as just described, at 12 gaze directions for horizontal and for vertical saccades (Fig. 5). Donders' law was better obeyed at gaze positions with the modified coil—less so with horizontal (Fig. 5A versus 5B) than with vertical (Fig. 5C versus 5D) saccades.

Figure 6 demonstrates the variability of the recordings on two different days from the modified and the original coils (right eye of subject S3, same coil). The inset depicts the start and the end position of the 40° saccades. Qualitatively, the torsional component measured on the two different days with the modified coil seemed more consistent in direction and amplitude than that recorded with the original coil (median torsional tracings of up to 10 repetitions). A slow drift after saccades was less common with the modified coil, as shown qualitatively in Figures 6E and 6F. Considering all subjects, however, there were no statistically significant differences between the torsion measured in the two sessions with either the modified or the original coil.

Figure 7 shows the torsional component of eye movements analyzed in different gaze regions. Horizontal saccades of 10°, 20°, and 40° amplitudes (Figs. 7A, 7B) were analyzed separately at 20° elevation, 20° depression, and straight-ahead gaze. Regardless of which type of coil was used, there was approximately 6° torsion with 40° saccades, 3° torsion with 20° saccades, and 1.5° torsion with 10° horizontal saccades in elevation. In depression, the torsion was less, 4° torsion with 40° saccades, 2° torsion with 20° saccades, and 1° torsion with 10° horizontal saccades, respectively. Because Listing's plane was predominantly rotated upward in the subjects (Fig. 3), there was more of a torsional change with horizontal saccades (Figs. 3A, 3B), which is reflected in the vertical component of primary position, than with vertical (Figs. 3C, 3D) saccades, which is reflected in the horizontal component of primary position.

With vertical saccades, the pattern of torsion between the modified and original coils differed considerably (Figs. 7C, 7D). With the original coil, more torsion change occurred when saccades were made in the nasal than in the temporal field of gaze. This increase of torsion toward the nose, implying cyclovergence, was seen with the original coil, but only with vertical saccades. With the modified coil, however, there was slightly more torsion at the right than the left gaze. In contrast, no cyclovergence was noted when comparing the torsion of the left and right eyes (Fig 7C). Again, note that the torsion change shown after horizontal saccades (Figs. 7A, 7B) can only be used to infer the vertical component of primary position, and the torsion change shown after vertical saccades (Figs. 7C, 7D) can only be used to infer the horizontal component of primary position.

We also investigated changes in intrasaccadic torsion, looking at the 40° saccade trials. For all three subjects, Figure 8A summarizes the torsion (all dashed lines) associated with 40°

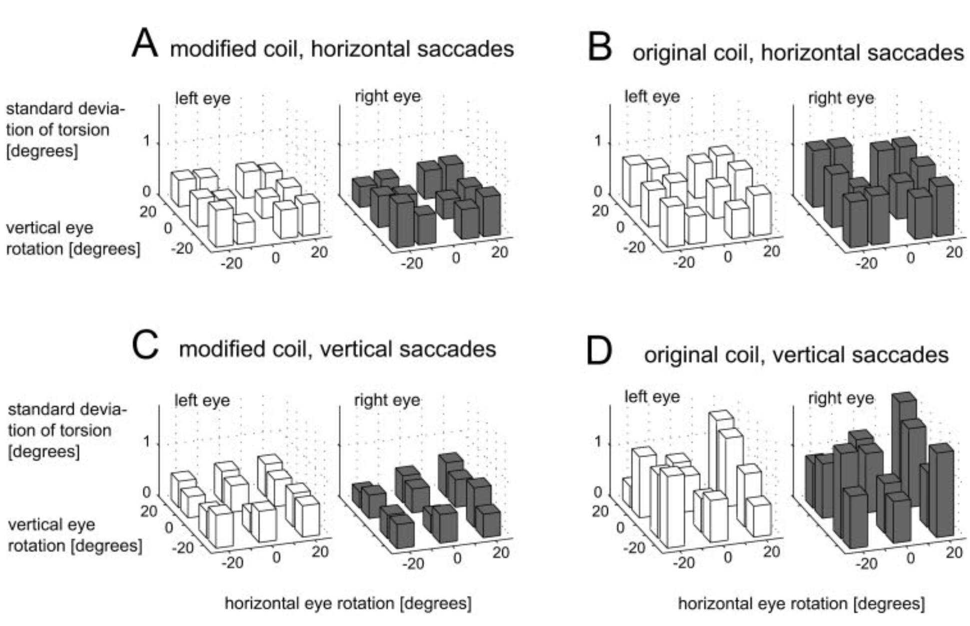

FIGURE 5. Donders' law (the standard deviation of torsion at each gaze direction; *z*-axis) was better obeyed with the modified (**A**, **C**) than the original (**B**, **D**) coil.

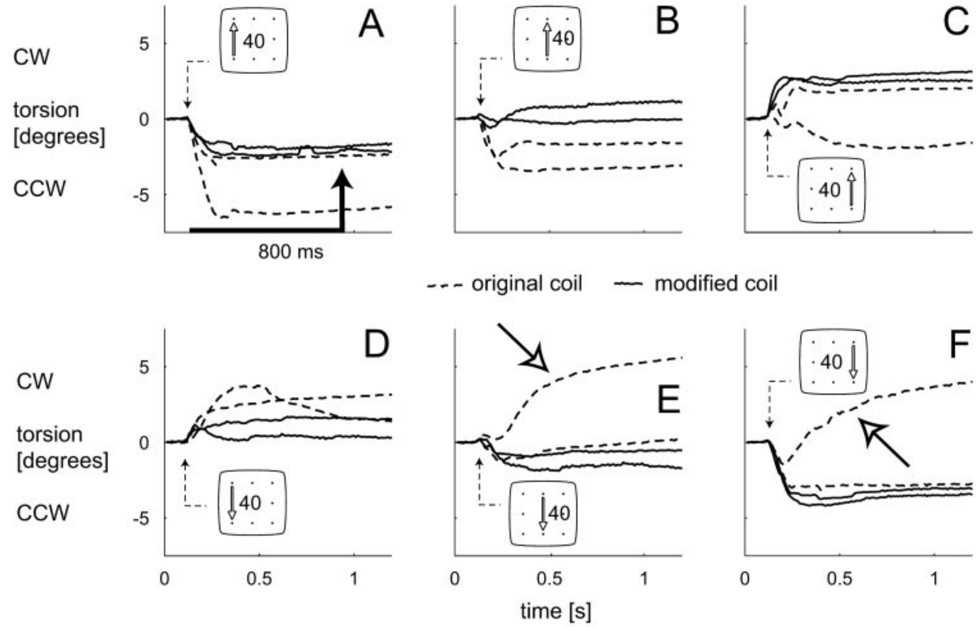

FIGURE 6. Median traces of the right eye torsional component associated with 40° vertical saccades in two different sessions (one tracing for each session) with subject S3. *Insets*: start and end positions of the 40° saccades that corresponded to the torsional tracing. Regarding the torsion at 800 ms after the beginning of the saccade (**A**, *large arrow*), the modified coil showed a smaller difference in torsion between the two sessions compared with the original coil in all panels. There was also a bigger difference in the amount and direction of postsaccadic torsional drift between the sessions with the original coil (**E**, **F**, *open arrows*). CW: clockwise; CCW: counterclockwise rotation.

horizontal saccades (solid line) along the horizontal meridian. The median traces show that only subject S1 (see closed arrows) had a clear blip—that is, a dynamic change in torsion during the saccade that was out of the range from that expected from the change in static torsion associated with the change in eye position produced by the saccade itself (Fig. 8A, open arrows). The extent of blips was not influenced by the degree of elevation. There was also little difference in overall blip torsion between using the modified and the original search coil with horizontal saccades. Figure 8B shows that for vertical

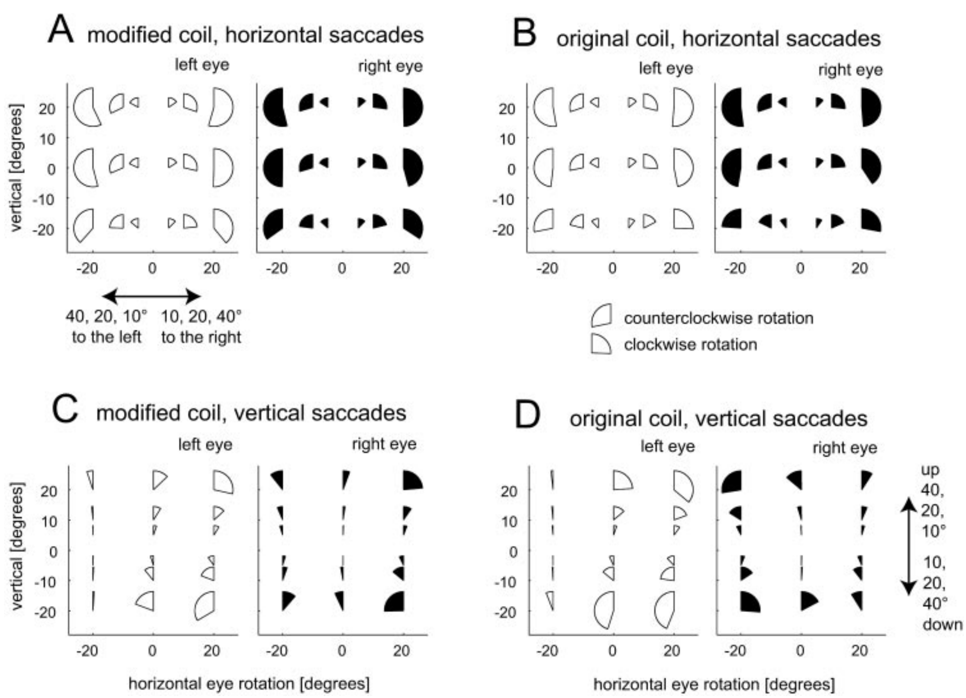

FIGURE 7. Torsion analyzed in different gaze regions (data averaged over two sessions for all three subjects). The torsional difference between the beginning and at 800 ms after the beginning of saccades was calculated. In each panel, each origin of the sector appears at the end point of a saccade. There are three increasing sizes (radius) of sectors: for 10°, 20°, and 40°, respectively. For each amplitude saccade, six saccade types are represented (**A**, 40°: from −20/20 to the right to 20/20, the sector is placed at 20/20, and from 20/20 to the left to −20/20, placed at −20/20; 20°: from −10/20 to the right to 10/20, placed at 10/20, and from 10/20 to the left to −10/20, placed at −10/20, and so on). The amount of clock hours of the sectors indicates the amount of torsion in degrees (e.g., three hours = 3°). There was more torsion with horizontal (**A**, **B**) than vertical (**C**, **D**) saccades, independent of the type of search coil. For vertical saccades, with the original coil (**D**), more torsion was present in the nasal gaze field (mirrored at the nose), whereas with the modified coil (**C**), the torsion depended less on horizontal eye position.

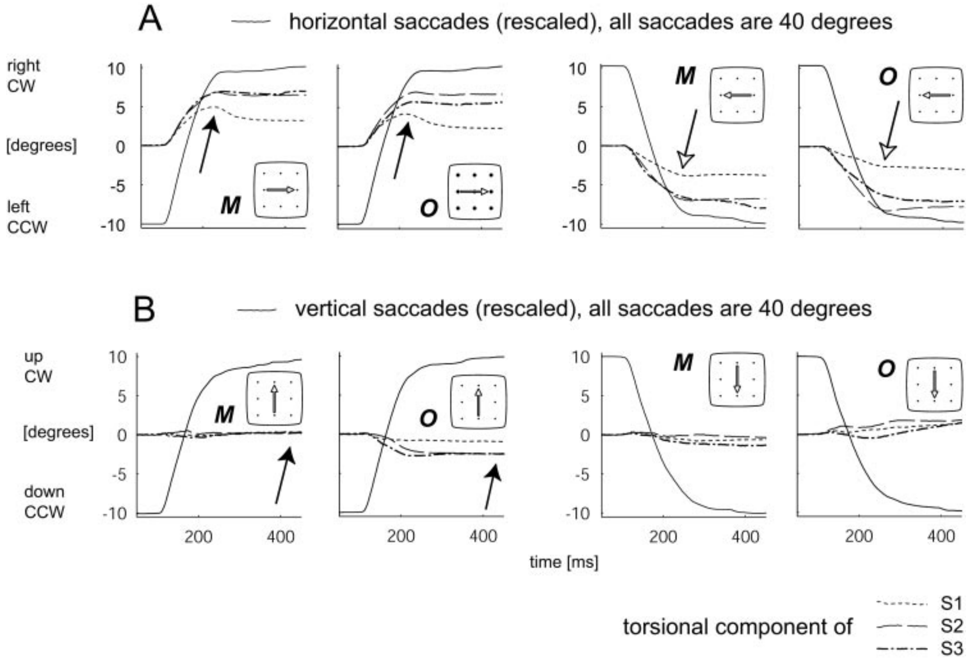

FIGURE 8. **(A)** Right eye 40° horizontal saccades (median traces of three subjects) with the modified (*M*) and the original (*O*) coil. *Insets*: start and the end positions of the horizontal saccade (*solid*; actual 40° saccade rescaled to 20° on the ordinate) that corresponded to the torsional tracing. Blips were sometimes present in subject S1 (*filled arrows*) but not in all saccades (*open arrows*). There was no difference in static torsion between the modified and the original coils, which corresponds to the similar location of the vertical component of primary position measured with both types of search coils. **(B)** Right eye 40° vertical saccades. No clear blip was present in either of the subjects. The static torsion after saccades was more pronounced with the original than the modified coil (*filled arrows*) corresponding to the more temporal location of primary position with the original search coil.

saccades, too, there was little difference in blip torsion between the original and the modified search coil. However, as shown earlier, the change in static torsion with the different fixation positions was greater with the original coil than with the modified coil (closed arrows) and accounts for the differences in the location of primary position (see also Fig. 3).

DISCUSSION

In this study, the temporal rotation of Listing's plane, as reflected in the horizontal component of primary position, differed with the type of search coil (Fig. 3). The difference between the values of the primary positions of the right and the left eyes were less with the modified coil than with the original coil with either horizontal or vertical saccades. The horizontal component of primary position, measured with the original coil, varied more with saccade direction. There was more temporal rotation of Listing's plane when measured during horizontal than vertical saccades. We do not know of any physiological base for primary position to depend on how the eye reaches a given position in the orbit—that is, depending on the direction of the preceding saccade. Therefore, there may be more torsional artifact associated with the original coil.

What might be the mechanical explanations for the difference between the two coils? Certainly, when the eye rotates upward, the upper eyelid may interfere with the upward motion of the nasally exiting wire. Then, the still elevating eye globe could produce a relative incyclorotation of the coil and thus lead to a more temporal position of the horizontal component of primary position of Listing's plane. In contrast, the greatest difference between the coils was in the horizontal component of primary position as measured after horizontal saccades (Fig. 3B). This may relate to the fact that the difference in the effects of the lids on the wire between up and down horizontal saccades could be quite large and hence could lead to relatively more intorsion in up gaze and/or relatively more extorsion in down gaze (depending on how the exit wire was hindered by the upper or lower lid).

Based on the results of this study, one should be cautious when interpreting the horizontal component of primary position of Listing's plane using scleral annuli, as there may be some mechanical artifact associated with lid movement. Few data are available on the location of primary position when measured with other eye movement recording techniques. Using a video method, Maxwell et al.[6] showed in one subject that there was no difference in torsional eye position between the left and right eyes with vertical pursuit. This implies that the horizontal component of primary position was near zero. Hering[7] reported that afterimages could be used for subjective testing of relative torsion of the eyeball about the axis of line-of-sight. With this technique, primary position seemed to be almost straight ahead. The vertical line of the afterimage cross remained vertical when the subject looked up or down. The observations of both Maxwell et al. and Hering are consistent with the data obtained with the modified coil (Fig. 3).

With the original coil, cyclorotation with vertical eye movements was minimal at 20° temporal gaze for both eyes (Fig. 7D). Incyclorotation with up gaze and excyclorotation with down gaze gradually became greater with the eyes in more nasal positions, which corroborates results from a previous study using conventional search coils.[8] Thus, quantitative differences among previous studies in the amount of the temporal rotation of Listing's plane may be explained by the fact that either more horizontal or more vertical saccades were used during the paradigm.[8–10] A more temporal rotation of Listing's plane is also present during convergence on near targets[11–13] or by prismatically induced vergence (base out prisms).[10,14] One might ask whether this change in the orientation of Listing's plane with convergence is related to an artifact of using more adducted eye positions for the measures of torsion. There is still, however, a 5° outward rotation of the horizontal component of primary position of the nonconverging eye during convergence of the fellow eye when torsion is measured during fixation at the same orbital positions.[15] The change in Listing's plane with convergence has been attributed to a change in central innervation, perhaps primarily of the inferior oblique muscle.[16]

Listing's planes were thinner with the modified search coil—that is, with a smaller standard deviation of torsion from the fitted plane, than with the original search coil. With the modified coil the thickness of Listing's plane was as small as reported in rhesus monkeys,[17] in which three-dimensional ocular rotations are measured with search coils that are surgically attached to the sclera. Thus, previous search coil studies on the validity of Listing's law may have underestimated how strictly this law is actually obeyed in humans. In addition, we have confirmed several findings of De Souza et al.[5] who found that Listing's plane measured with the original coil is thicker and the twist factor greater with vertical than with horizontal saccades. In our experiments, the twist factor was larger with vertical saccades, and difference held true with both types of coils (Fig. 4B). Finally, only in the horizontal component of primary position, and then only after horizontal saccades (Fig. 3B), did the original coil show a bigger difference between the two sessions than did the modified coil. Therefore, when using the original coil and recording horizontal saccades, the torsional component of eye movement may fluctuate more from experiment to experiment. This could be due to greater slippage of the original coil.

We also compared differences between the two types of coils in the amount of torsion made during saccades. We specifically looked for blips (i.e., torsion during or just after saccades) that were above or below that predicted from any change in torsion that would be expected from the new fixation position after the saccade.[18] Blip torsion was inconsistent and not present in all subjects (Fig. 8). Our results, however, do not tell us whether the difference between the amount of blip torsion shown by the two eyes during a single saccade is due primarily to differences between the types of coils (and hence is at least in part artifactual) or is due to actual differences between the two eyes, because different muscles are activated. Even so, blip torsion cannot explain the difference between the two types of coils in the amount of torsion associated with fixation at different eye positions.

Measurements of ocular torsion have become increasingly important in both research and clinical applications. Scleral search coils are considered to be the gold standard for eye movement measurement. Our study did not show one type of coil to be better than another, because we had no objective gold standard for the absolute torsional orientation of the eye. Both Donders' and Listing's laws, however, were better obeyed with the modified coil. The between-subject variability of torsion in the two sessions was also slightly lower with the modified coil (Fig. 3). In these respects, the modified coil probably gave a more accurate measure of static eye torsion. In addition, there is a need to develop a wireless scleral coil in future.

In conclusion, our results indicate that measures of eye torsion (and the orientation of Listing's plane) differ depending on the orientation of the exiting wire from the search coil, and also that the results depend on the horizontal or vertical direction of saccades. Overall, the results suggest that the modified coil (wire exiting inferiorly) gives a more veridical estimate of static eye torsion and hence is less subject to artifact, probably because there is less mechanical interaction with the eyelids. Ultimately, comparison of torsion measured with noncontact video methods will help resolve the problem of artifacts from scleral search coil annuli.

Acknowledgments

The authors thank Dale C. Roberts and Adrian Lasker for technical assistance.

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