Torsion and Stereopsis

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ABSTRACT

The perceptual correlates of sensory cyclofusion have received little attention. However, they are easily elicited by asking patients with torsion about perceived slant of the visual world, and by watching how they hold the Titmus or Randot book. Sensory cyclofusion induces two types of perceptual aberrations. First, it rotates the plane of maximal stereoscopic volume in the pitch plane. As such, patients with large degrees of disconjugate binocular torsion can overcome a cyclodisparity by slanting the Titmus book to align the vertical images of the object with those of the retinas. Second, patients may report a perceived slant of vertical images and of the ground plane in three-dimensional space, so that the ground and the visual world appear to be slanted toward or away from them. Patients undergoing oblique muscle surgery should be examined pre- and postoperatively for corollary perceptual shifts in their stereoscopic perception of three-dimensional space.

INTRODUCTION

Ocular torsion is a common accompaniment of strabismus and its surgical treatment.1-3 While the problem of torsional diplopia has received considerable attention, there exists a prevailing notion that small amounts of ocular torsion that fall within the range of sensory cyclofusion are often not problematic.4 In patients with superior oblique palsy, for example, it is often stated that monocular extorsion of less than 5° falls within the range of sensory cyclofusion (i.e., fusion at the cortical level which occurs with no associated torsional movements of the eyes).5,6 While sensory cyclofusion is generally treated as a two-dimensional process (i.e., fusion of two images when one or both images are tilted in the roll plane), sensory cyclofusion also alters perception of three-dimensional space in the pitch plane.6 Sensory
cyclofusion produces two perceptual alterations in stereoscopic vision, which generally go unrecognized unless patients are questioned specifically.

TORSION AND STEREOPSIS

Large degrees of monocular or binocular torsion that may be incompatible with single binocular vision are not necessarily incompatible with excellent stereoacuity. With torsional cyclodisparity, the plane of maximal stereoscopic volume is slanted in the pitch plane (Figure 1). Slanting a vertical object with its top away from the observer will induce an image extorsion in each eye. When the eyes are extorted, a binocularly viewed object would have to be slanted with its top away to create the same horizontal disparity that a vertical object creates in normal individuals. When the eyes are intorted, a binocularly viewed object would have to be slanted with its bottom away to create maximal horizontal disparity (Figure 1). Under these circumstances, the plane of maximal stereoscopic volume is now slanted in the pitch plane and the degree of slant corresponds incrementally to the degree of cyclodisparity. Thus, stereoscopic slant is a binocular correlate of vertical cyclodisparity.

Conversely, viewing a slanted vertical object at near will evoke a stereoscopic slant under binocular conditions, and a torsional cyclodisparity under monocular conditions (Figure 2). For this reason, it is important to observe how the patient spontaneously positions the booklet when performing a stereoacuity test. If you observe how the patient spontaneously angles the Titmus® or Randot® booklet relative to the visual axis, you will find that the booklet is held in the necessary slanted position to recreate normal horizontal disparity. (The normal plane of maximal stereoscopic volume is not orthogonal to the visual axis, but slanted top away so that a line projecting downward from the booklet to the feet. This angle corresponds to the vertical horopter as defined by Helmholtz. I have performed inferior oblique anteroplacements in a child with bilateral DVD and no preoperative torsion. On the first day postoperatively, the child complained of bilateral image intorsion yet had 100 seconds/arc stereoacuity. Because both of her eyes were intorted, this child’s plane of maximal stereoscopic volume was now slanted in the pitch plane (Figure 2). When identifying the Titmus® circles, she angled the top of the booklet toward her and viewed the smallest stereo circles almost tangentially in order to induce a binocular image.
intorsion to match her fundus intorsion. This surgically induced stereoscopic slant diminished over several weeks. Such are the hidden consequences of successful oblique muscle surgery!

ACQUIRED TORSION

Since stereoscopic slant is the binocular perceptual correlate of binocular cyclo-diplopia, it follows conversely that acquired ocular torsion would induce a slant in a pitch plane. As such, acquired ocular torsion can also induce a perceived slant of vertical images in the pitch plane (Figure 3). According to Ogle, a large degree of stereoscopic slant is necessary to induce a small degree of disconjugate torsion, so that even a small amount of ocular torsion can induce a perceived stereoscopic slant. For any given amount of disconjugate torsion, the induced stereoscopic slant increases as the fixation distance decreases. I recently performed an inferior oblique recession on an adult with an acquired superior oblique palsy and no preoperative torsion. Immediately postoperatively, he stated that “it felt like I was walking downhill.” This symptom corresponds to a backwards stereoscopic slant.

FIGURE 2: Even severe degrees of ocular torsion are compatible with normal stereoacuity when the object under examination can be slanted to realign its monocular images with the horizontal retinal meridians. The upper figure shows bilateral intorsion of the globes, which causes the images of an orthogonal (i.e., perpendicular to the visual axis) object to be extorted (dashed lines) relative to the true vertical retinal meridians (solid lines). By pitching the object forward (i.e., angling the top toward the observer), the visual image of the vertical object is brought into alignment with the horizontal retinal meridians, allowing stereoscopic detection of binocular disparity cues so that horizontal disparity is restored and stereopsis is maximized. The lower figure shows bilateral extorsion of both globes, which causes the images of an orthogonal object to be intorted relative to the vertical retinal meridians. By pitching the object back (i.e., angling the top away from the observer), the visual image of the vertical object is brought alignment with the vertical retinal meridians, allowing stereoscopic detection of horizontal disparity cues.
TORSION AND STEREOPSIS

FIGURE 3: The slant illusion produced by ocular torsion produces perceptual symptoms in patients with superior oblique palsy. The upper figure shows extorsion of the right eye corresponding to a right superior oblique palsy (solid line represents retinal vertical meridian, dashed line represents intorted retinal image of vertical object viewed in the sagittal plane).

The lower figure shows how monocular extorsion induces a perceived slant of the visual world, causing midline vertical objects and the ground plane to appear to be slanted toward the observer. Thus, to patients with superior oblique palsy, it may appear that they are walking uphill when walking on flat ground, while to patients with monocular intorsion following surgery for superior oblique palsy it may appear that they are walking downhill.

of the visual world (Figure 3). However, he did not mention this symptom until specifically asked, and it resolved over several days. Lindblom et al. found that adults with acquired superior oblique palsy perceive a vertical rod held in the sagittal plane to be slanted forward. Thus, even an monocular torsional disturbance is sufficient to produce a stereoscopic slant in the pitch plane.

If sensory cyclofusion incorporates a stereoscopic slant in the pitch plane, why are most patients with ocular torsion asymptomatic? The neurophysiologic mechanisms involved in stereoscopic slant perception are complex. Howard and Kaneko have carefully studied this psychophysical phenomenon using large random-dot stereoscopic displays with various types of shear disparity. They found that that an isolated shear disparity of vertical lines will induce a stereoscopic slant, while a cyclodisparity of both vertical and horizontal lines fails to induce a perceived slant of the visual environment. They concluded that the perceived inclination of a large, isolated, textured surface is derived from the difference between horizontal and vertical shear disparities. (According to this nomenclature, a horizontal cyclodisparity refers to a cyclodisparity of vertically oriented lines that are sheared horizontally, while a vertical cyclodisparity refers to a cyclodisparity of horizontally oriented lines that are sheared vertically.) They reasoned that a centrally placed surface inclined in depth about a horizontal axis passing through the fixation point produces an isolated cyclodisparity of vertical lines at right angles to the horizontal axis of rotation. Thus, a slanted visual image in the sagittal plane will induce an isolated vertical cyclodisparity with no horizontal cyclodisparity. Since there is no natural stimulus to produce cyclodisparity of the horizontal meridians, when the brain recognizes cyclodisparity of horizontal lines, it attributes this effect to ocular torsion rather than to slant. For accurate stereoscopic perception, the brain has learned to subtract out the cyclodisparity of horizontal meridians from the cyclodisparity of vertical meridians to gauge object slant in three-dimensional space. It is as if the visual system can compare all orientations; when all meridians are twisted, the brain knows that the eyes are...
torsionally rotated and does not register a visual slant. Nevertheless, isolated linear features that approximate the vertical retinal meridians can appear slanted in space when there is ocular torsion. The reader can appreciate this effect by placing a Dove prism before each eye (if you look through a Dove prism and rotate it, the image rotates through an angle twice as much as the prism) to induce disconjugate retinal image torsion. This perceived slant in the visual world is particularly evident in the ground plane, causing the ground to appear as if the subject is looking uphill when the visual images are intorted, and looking downhill when the visual images are extorted (Figure 4). This stereoscopic slant would suggest that the brain does not erase all stereoscopic effects of monocular or binocular torsion in three-dimensional space. Whether sensory or motor alterations are responsible for the resolution of this stereoscopic perceptual alteration remains to be determined.

When performing oblique muscle surgery in patients with stereopsis, it is important to compare how the patient holds the Titmus® or Randot® book pre- and postoperatively since the procedure will surgically rotate the patient’s stereoscopic world in the pitch plane! Acquired ocular intorsion will cause patients to pitch the top of the stereo book toward them, while acquired extorsion will have the opposite effect. In patients with congenital strabismus and course stereopsis, binocular cyclodisparity associated with primary oblique muscle overaction should also rotate the plane of maximal stereoscopic volume in the pitch plane. Imagine the stereoscopic world of patients with craniosynostosis, bilateral pulley heterotopia, and large degrees of bilateral fundus extorsion! Do some of these patients inhabit a warped stereoscopic world in which the plane of maximal stereoscopic volume is “everted” relative to the ground plane?

CONCLUSION

The effects of ocular torsion are often considered inconsequential when sensory cyclofusion can overcome the effects of cyclodisparity in the roll plane. Nevertheless, ocular torsion and sensory cyclofusion both come at a cost. Ocular torsion rotates the plane of maximal stereoscopic volume, and sensory cyclofusion induces a subjective stereoscopic sensation of slant. By observing how the patient slants the Titmus book preoperatively and postoperatively, and by asking patients how they perceive the world before and after oblique muscle surgery, we can begin to unlock the third dimension sensory cyclo-

FIGURE 4: By viewing the world through Dove prisms, a binocular retinal image torsion can be induced. The upper figure shows bilateral image extorsion (dashed lines) relative to the true vertical meridians (solid lines). The lower figure shows the resulting slant in the perceived vertical and in the perceived ground plane.
fusion, better define the subjective correlates of torsion, and come to understand the perceptual effects of ocular torsion.

REFERENCES


Key words: stereopsis, torsion, IVth nerve palsy.