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A new model of functional astigmatism

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ABSTRACT—Astigmatism is a refractive condition in which there is a variation of power in the different meridians of the eye. The cause of the condition has been subject to considerable discussion and debate over the years. Some consider it to be a structural anomaly following genetic and age patterns while others conceive of it as being functional in origin. To complement the more traditional views, this paper proposes a new and more encompassing model of functional astigmatism involving an interrelationship among the factors of eye scan, head scan and head posture with implications that changing the elements within this triad can have a positive effect in reducing astigmatism.

KEY WORDS—astigmatism; with-the-rule; against-the-rule; oblique astigmatism; eye scan; head scan; head posture

Astigmatism has been of interest since Thomas Young first discovered, measured and described the condition in himself in 1801.[1] Wharton Jones, in 1855, attributed it to a defect in the cornea.[2] It has since been found to be a condition that is quite prevalent.[3] The enigma is why it occurs. Is it mainly a structural anomaly following genetic or age trends or is it primarily functional in nature, responding to use? Many have taken sides on this issue and have used clinical observations and research studies to substantiate their differing points of view.[4,5,6,7,8,9,10,11,12,13,14] Interestingly, Emile Javal,[15] one of the early and noted researchers in the area of astigmatism, observed over a century ago, that it was a common occurrence for astigmatism to decrease in strabismic patients after they had undergone either extraocular muscle surgery or stereoscopic exercises (orthoptic training).

My involvement in this area was sparked by the appearance of relatively rapid and unexpected astigmatic changes in individuals of varying ages whose refractive status had been stable for many years. It was also noted that many myopic and presbyopic individuals did not develop less with-the-rule (-cyl.×180) or more against-the-rule (-cyl.×90) astigmatism as recent research studies would lead one to expect.[16,17,18,19] In addition, it was observed that many changes in astigmatism, often of low degree, appeared to be coincident with specific changes in work, study or TV habits.

This element of astigmatic change was investigated over a period of many years. During this time, patients who demonstrated changes in their astigmatic status were questioned extensively and asked to demonstrate, often through the use of a visual imagery approach, how they performed their major visual tasks. This included determining how they sat, how they held their heads, and how they responded visually to secondary elements involved in their work that required looking up, down, or to the sides from what they were doing. (See Appendix for suggestions on using a visual imagery approach in order to determine how major visual tasks are performed.)

This long-term investigation revealed a distinct relationship between the development of functional astigmatism (or changes in existing astigmatic status) and persistent changes within an operational triad consisting of visual scan (eye movement free of accompanying head movement), head scan (eye movement yoked to head movement), and head posture (a combination of angle, rotation and tilt of the head in relation to gravity). (See Figures 1, 2, and 3.)

A subsequent research study on 45 patients revealed that altered

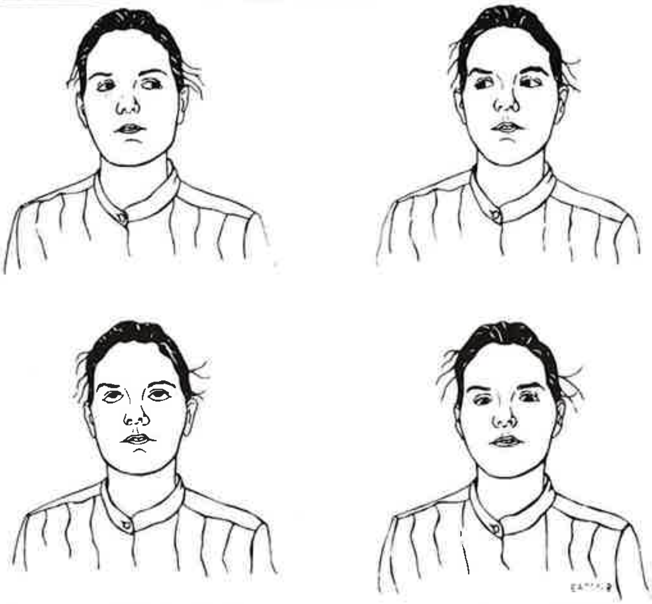
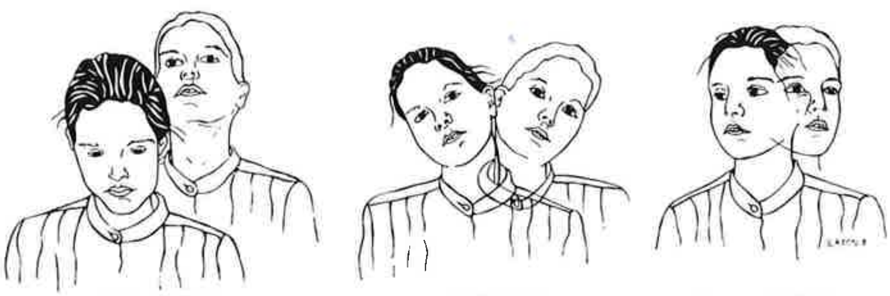


Figure 1: VISUAL SCAN—Eye movement free of accompanying head movement.

Figure 2: HEAD SCAN—Eye movement yoked to head movement.



HEAD ANGLE HEAD TILT HEAD ROTATION

Figure 3: HEAD POSTURE—The major elements of head movement around the x, y, and z axes.

eye usage not only could trigger astigmatic changes but could do so in as short a period of time as four months. A second study, in turn, indicated that it was also possible to use refractive astigmatic data to predict the eye scan/head scan/head posture relationship.[20]

A major implication of this investigation was that persistent limitation of eye movement on a meridional basis was seen to precipitate the development of astigmatism with the strongest power forming in the meridian of greatest "head scan," where eye and head movement tend to be yoked together. In other words, the visual system appears to become more myopic (or less hyperopic) in the meridian in which the potential for the eyes to scan free of head movement is limited or restrained as compared to the meridian 90° away.

The key relationships are as follows:

Key Elements

1. With-the-Rule (-cyl.×180) astigmatism appears to relate to a greater observed preference for visual scanning (free of head movement) in the horizontal meridian.
2. Against-the-Rule (-cyl.×90) astigmatism appears to relate to a greater observed preference for visual scanning in the vertical meridian.
3. The overall magnitude of astigmatism appears to relate to the degree of difference in the visual scanning status between the predominantly visual (or eye) scanning meridian and the predominantly head scanning meridian. Less astigmatism indicates less of an operational difference between meridians. Little or no astigmatism appears to develop when the eye scan—head scan preferences (whatever they may be) are approximately equal in all meridians.
4. Astigmatic Anisometropia is a condition in which there is a difference in astigmatism between the two eyes. This appares to develop as a result of a persistent mismatch between the structural midline of the head and the operational visual midline as represented by an imaginary line bisecting the angle formed by the lines of sight as they fixate on a target. (See Figure 4.) This kind of mismatch can be elicited by working off to the side without fully rotating the head, keeping work directly ahead while rotating the head to one side, or a combination of the two. In any case, it was found that the eye

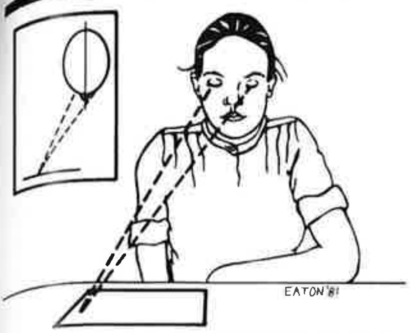


Figure 4: A mismatch between the structural midline of the head and the operational visual midline.

Figure 5: The eye closest to being directly in line with and perpendicular to the task develops less astigmatism.

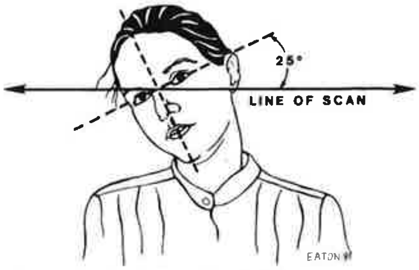


Figure 6: A 25° mismatch between the line of scan and the "horizontal" plane of the eyes.

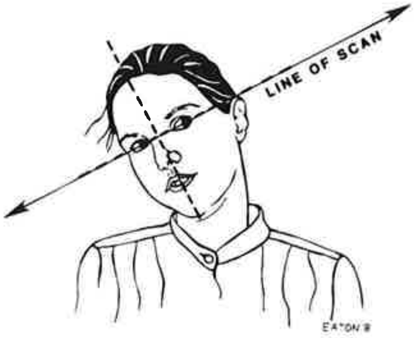


Figure 7: Coincidence of the visual scan meridian and the "horizontal" plane of the eyes results in W. R. astigmatism even when the head is persistently tilted.

Figure 8: A visual scan meridian that is perpendicular to the "horizontal" plane of the eyes results in A. R. astigmatism even when the head is persistently tilted.

that persistently sights across the facial midline tends to develop more astigmatism. In effect, astigmatic anisometropia becomes the structural ocular indicator of the position of a decentered functional "cyclopean eye" as it is used as a base for different meridional scanning styles.

The eye that is consistently closest to being directly in line with and perpendicular to the task appears to develop less astigmatism. The closer that eye is to true perpendicularity with the task, the closer it will be to having little or no astigmatism. (See Figure 5.)

5. Oblique Astigmatism—Astigmatism is usually considered to be oblique when the principal meridians lie between the 30th to 60th or the 120th to 150th meridian.[21] Since this author has always been impressed with the fact that so many astigmatic axes measure exactly 90° or 180°, for the purposes of this paper axes that are not exactly vertical or horizontal will be considered to be oblique.
6. Parallel Oblique Astigmatism is a condition in which the axes of astigmatism are the same in each eye, both being oblique. This appears to be due to a consistent obliquity in visual scanning that is related to either an angled positioning of the task, an angled position of the head, or some combination of both. It is specifically caused by a mismatch between the geometry of the head position (a right or left tilt of the head) and the corresponding geometry (or placement) of the task.

   Astigmatism of -cyl.×25, for example, would indicate that the consistent line of scan of the predominantly visual scanning meridian is 25° from the "horizontal" plane of the eyes (a plane at the level of the two eyes). (See Figure 6.)

   If, however, the tilt of the head and the tilt of the task are similar so that the "horizontal" plane of the eyes and the visual scanning meridian are coincident, the resulting astigmatism will tend to be with-the-rule (-cyl.×180) rather than oblique. (See Figure 7.)

   Similarly, if the preferrred visual scanning meridian is perpendicular to the "horizontal" plane of the eyes (regardless of head tilt) the resulting astigmatism will tend to be against-the-rule (-cyl.×90). (See Figure 8.)
7. Symmetrical Oblique Astigmatism is a condition in which the axes of astigmatism are more or less symmetrically extorted or intorted from the vertical. This appears to result from an interplay among the following: the frontal plane of the head (facial plane), the primary position plane (a plane at the level of the two eyes that is perpendicular to the frontal plane of the head), the plane of regard (a plane connecting the lines of sight as they

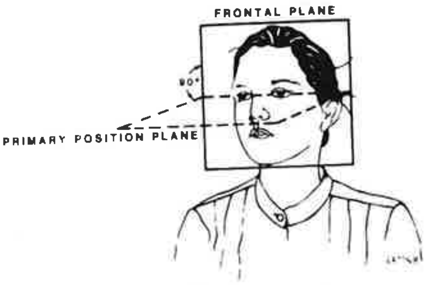


Figure 9: Relationship between the Frontal Plane of the head and the Primary Position Plane.

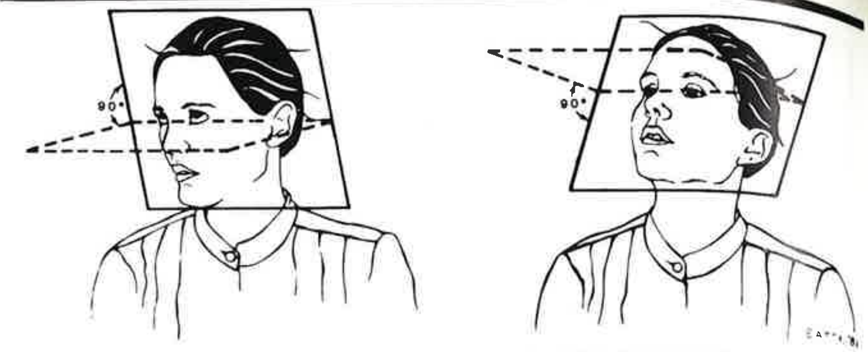


Figure 10: Scanning above or below the Primary Position Plane as a result of persistent head angling.

fixate the object of regard), and the preferred scan (horizontal, vertical or oblique). (See Figure 9.)

Symmetrical oblique astigmatism appears to result from a consistent disparity (or mismatch) between the primary position plane (P.P.P.) and the plane of regard. It is caused by a persistently angled relationship between head position and the position of the habitually scanned fixation targets. (See figure 10.)

In binocular individuals, presistent scanning above the P.P.P. appears to result in intorted axes. Vertical eye scanners are noted to exhibit intorted axes closer to the vertical while horizontal eye scanners are seen to exhibit intorted axes closer to the horizontal. The further the average scan is above the P.P.P. the closer the axes appear to approach O.D. 45 and O.S. 135.

Similarly, binocular individuals who persistently scan below the P.P.P. tend to reveal extorted axes. Vertical eye scanners are noted to exhibit extorted axes closer to the vertical while horizontal eye scanners are seen to exhibit extorted axes closer to the horizontal. The further the average scan is below the P.P.P. the closer the axes appear to approach O.D. 135 and O.S. 45.

It has been noted as well that for those whose work involves much near-to-far scanning, the location of the greater part of the slope of the scan (whether it is above or below the P.P.P.) determines the type of astigmatic obliquity (either extorted or intorted). It was also observed that "chin down" scanners do not appear to have to scan as much above the P.P.P. to achieve axes 45–135 obliquity as "chin up" scanners have to look below the P.P.P. to achieve axes 135–45.

Finally, it was noted that those who persistently resort to monocular seeing, whether due to strabismus or inefficient (fragile) binocularity tend to demonstrate the reverse obliquity. For example, "chin down" monocular scanners usually demonstrate extorted axes while "chin up" monocular scanners will tend to reveal intorted axes.

8. Asymmetrical astigmatism is a condition in which the axes of astigmatism are neither parallel nor totally symmetrical. This appears to be due mainly to a combined oblique eye scan/head tilt relationship superimposed upon an angled (chin up or chin down) head position.
9. The extreme of asymmetry is seen in perpendicularly-opposing astigmatism where the astigmatism in one eye approaches vertical while that of the other approaches horizontal. This type of astigmatism appears to be evident in those who utilize a different type of scan for things done on the right side as opposed to the left side. In most instances, this is seen to be accompanied by poor binocularity.

Relationships

The long-term investigation that led to the development of the model and the studies that followed to substantiate it demonstrated a number of interesting factors. One of these was the apparent meaningfulness of small astigmatic changes of approximately .25 to .75 diopters as sensitive indicators of specific changes in work habits and eye usage.

A second factor had to do with relationships between astigmatism and contact lens wear. A number of hard and soft contact lens patients whose astigmatism had changed (without evidence of any corneal edema) pointed out that specific areas of discomfort caused them to alter their usual visual scanning habits. Hard contact lens patients, for example, who had difficulty gazing upwards while wearing their lenses tended to become head movers when looking up and concurrently demonstrated an increase in with-the-rule astigmatism. One soft lens patient, in particular, had diminished acuity on lateral gaze due to lens decentration triggered by narrow and tight outer lid angles. This patient compensated for the difficulty by becoming a greater head mover horizontally in order to maintain clear vision while concurrently developing against-the rule-astigmatism.

A third factor had to do with keratometry. Retinoscopic and subjective measurements were made to determine the total ocular astigmatism. In cases of discrepancy, the final reference was always made to the astigmatism found under subjective testing. Even though a significant relationship was seen between changes in eye scan habits and changes in total intraocular astigmatism, keratometric data, however, did not demonstrate this same consistency. Often there was little or no change at all. When keratometric findings did change, there appeared to be a significant time delay that was not found to be consistent from patient to patient. Why?

The fact that the meridional status in regard to eye movement relates to total ocular astigmatism implicates the extraocular muscles as a potential major mediating factor in the production of astigmatism. This is consistent with Javal's finding that astigmatism can be created by the least amount of pull on the skin of the lids similar to the action of the extraocular muscles. It is also consistent with the fact that astigmatism has often been reported to follow extraocular muscle surgery and eye exercises.[22,23]

It has also been noted that chalazia,[24] hemangiomas of the upper eyelid,[25] epibulbar dermoids[26] and advancing pterygiums[27] also produce astigmatic changes. These observations tend to implicate the cornea as another potential mediating factor in the formation of astigmatism.

Two questions, therefore, have to be raised. First, is there a relationship between corneal deformation and extraocular muscle action involving the formation of astigmatism and second, if so, why does this not show up in a consistent manner in keratometry?

The difference in astigmatism between the total intraocular and keratometric findings has been called residual astigmatism. Traditionally, this difference has been attributed to the shape, decentration, or tilt of the crystalline lens of the eye even though no definitive studies appear to be obtainable to demonstrate that lenticular astigmatism actually exists in an undiseased lens. Others have attributed residual astigmatism to the angle between the apex of the cornea and the line of sight.[28,29,30] Still others have indicated that most residual astigmatism can be accounted for by a tilt of the corneal cap.[31]

These hypotheses may account for some of the apparent inconsistencies between a given keratometric and a retinoscopic (or subjective) finding but none appears to adequately account for the relative inconsistency of central corneal keratometric readings in the face of significant concurrent changes in total ocular astigmatism.

In a recent controlled experiment Cuttone et al.,[32] created superiorly placed corneoscleral limbal masses and upper eyelid colobomas in a total of 20 rabbit eyes. Refractive changes were recorded over a one month period using retinoscopy, keratometry and photoelectronic keratoscopy. In most instances, the rabbits having had these procedures demonstrated an increased astigmatism. The astigmatic change as measured by retinoscopy was highly related to that found by photokeratoscopy using Δ P values (the algebraic difference between the most central and the most peripheral point in each of four meridians). No consistent effect was found in regard to central keratometry readings. This was accounted for by the investigators as being due to a flattening of the periphery of the cornea which is measurable by retinoscopic means as well as photokeratoscopy long before central corneal measures are affected.

Extraocular muscle action

Far more is unknown than is known about the workings of the visual process, yet so much is taken for granted. There are so many legitimate "whys" that should be considered and reconsidered. For example, as Simpkins[37] posed, why is the eyeball pliable? Why is the cornea more steeply curve than the rest of the globe? Why is the basic shape of the globe dependent upon the internal outward pressure of the intraocular fluids? Why is the center of rotation of the eye not coincident with the actual center of the globe? Why do the recti muscles pull from in front backwards and the obliques from behind forwards? Why are the recti inserted at varying distances from the limbus?

Is it possible that the action of antagonistic muscles can either stretch or squeeze the globe to literally lengthen or shorten the visual axis?

Is it possible that the difference in curvature of the cornea and sclera allows slight changes in the length of the visual axis to be sensitively reflected in corneal shape?

All the answers are certainly not available but the action of the extraocular muscles does appear to create forces that must be reckoned with. Since eye movement has been observed to be related to functional astigmatism, then the extraocular muscles should be considered to be involved in some manner in its creation. If this is so, then the accepted rules that appear to govern extraocular muscle action should also somehow relate to what has been observed.

It is not within the scope of this paper to analyze all the specific muscle actions but it can be stated that the known actions of the extraocular muscles do appear to be related to the formation of many forms of functional astigmatism. Symmetrical oblique astigmatism can be used as a case in point.

All eye movements, in general, are combinations of versions (yoked, parallel movements) and vergences (non-parallel, disjunctive eye movements). The interplay between versions and vergences as one scans to the right and to the left inside of infinity is called asymmetric vergence.

Torsion (or cyclotorsion) is a rotation of the vertical meridian of the eye using the line of sight as an axis. (See Figure 11.) There is no torsion in vertical and horizontal movemements from the primary position. Torsion arises from oblique eye movements. It also arises from lateral eye movements from a raised or depressed eye position. Torsion also arises from convergence.

Convergence induces an excyclotorsion which increases as convergence increases. Extorsion also increases as one converges above the primary position plane. It decreases as one converges below the primary position plane until at approximately 30–40° below the horizontal plane where a point of zero torsion is reached. As one converges further below this point intorsion increases.[34, 35, 36] Scanning on a "z" axis plane that is inclined with the top further from the subject also causes extorsion.[37]

Symmetrical cyclotorsion (binocular extorsion and intorsion) in a functionally binocular individual is normally compensated for a reverse torsional response to maintain fusion (compensatory cycloduction). If this torsion is not totally compensated for the result could be diplopia, suppression or a meridional aniseikonia. (See Figure 12.)

Interestingly, it has been long noted that even though cyclophorias are normally compensated for by the action of the oblique muscles there is less need for such compensation when oblique astigmatism is also present.[38] It can be implied, therefore, that oblique astigmatism might be a method for maintaining binocular parallelism of the vertical axes thereby reducing the need for a compensatory cycloduction, suppression or meridional aniseikonia.

It has also been noted that prescribing obliquely placed cylindrical lenses out-of-pattern, so that an artificial oblique astigmia is created, can be used as a device to counteract and reduce a cyclophoria.[39] Perhaps, therefore, the formation of a natural oblique astigmatism is nature's way of counteracting and reducing a persistent cyclophoria.

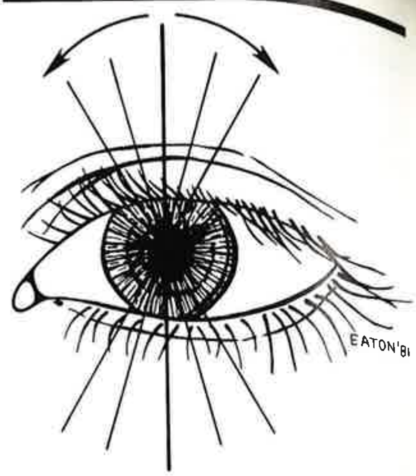
In binocular individuals the adaptive development of astigmatism appears to be related to the compensations that are made to cope with the cyclotorsion. For example, scanning (or converging) above the primary position plane induces a binocular excyclotorsion. To maintain fusion, there must be a compensating binocular intorting response. It is adaptation to this compensatory force that appears to precipitate the formation of intorted symmetrical oblique astigmatism.

A similar condition of excyclotorsion in a monocular individual, or in one who tends to suppress one eye under binocular stress, appears to result in an adaptation that is directly related to the primary direction of torsion since there is no compensatory cycloduction needed to preserve fusion. In this case the persistent chin down (above P.P.P.) scanner would tend to develop extorted symmetrical oblique astigmatism.

Similarly, parallel oblique astigmatism of any kind appears to represent an adaptation to primary rather than compensatory forces since the cyclotorsion of each eye is yoked to the other in the same direction in terms of a right or left binocular torsional effect. (See figure 13.) The normal response to this situation would be to reduce the stress by going in the direction of the stress. Therefore, the axes of astigmatism in these cases could be expected to correspond to the direction of the cyclotorsion, either dextro or levo.

In turn, a persistent difference in meridional eye scanning that is predominantly vertical or horizontal in relation to the task might be hypothesized to result in vertical or horizontal rather than oblique astigmatism since minimal *persistent* torsional elements of one specific type or another would be involved.

Astigmatism, therefore, can be viewed as being both a sensitive indicator of persistent restraint in eye movements and as an indicator of the types of compensations that are made for different kinds of persistent extraocular muscle action.



TORSION

Figure 11: CYCLOTORSION— A rotation of the vertical meridian of the eye.

Implications

Functional astigmatism, then, appears to be the physical ocular

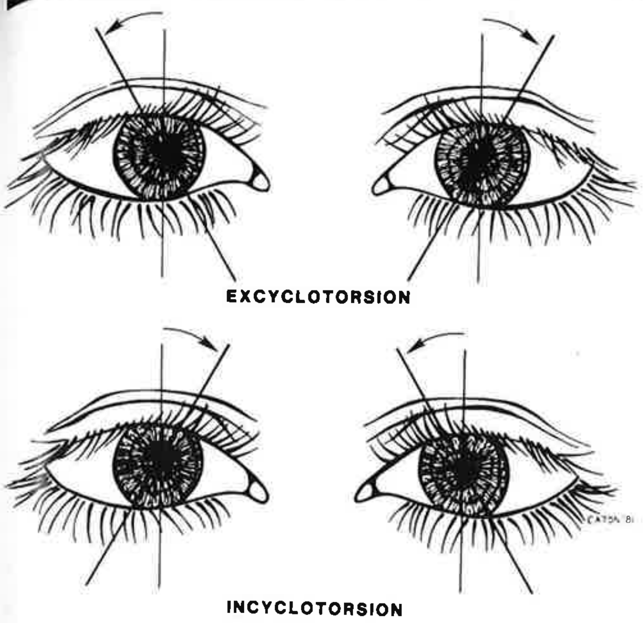


Figure 12: SYMMETRICAL CYCLOTORSION—Binocular excyclotorsion or incyclotorsion of the eyes.

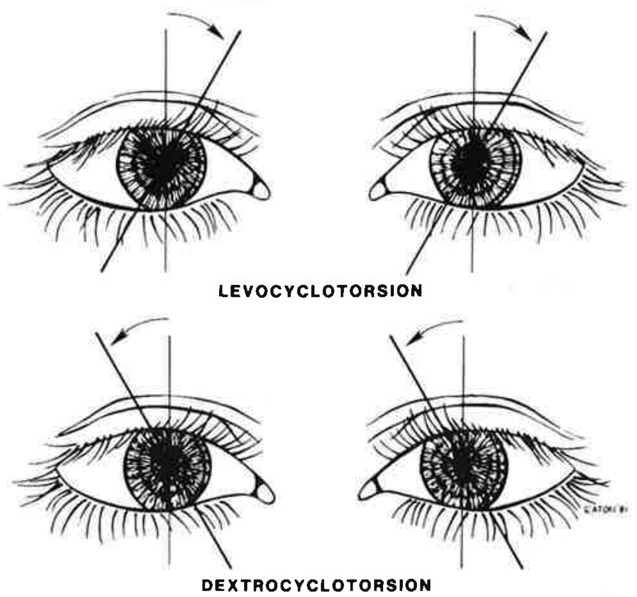


Figure 13: PARALLEL CYCLOTORSION—a unidirectional (left or right) cyclotorsion of the eyes.

sign (or effect) of a persistent difference in eye movement scanning patterns in one meridian as compared to the meridian 90° away. There are many factors that can precipitate this meridional difference in eye movement patterns.

For one thing, astigmatism is found in infants[40,41] and as if to substantiate the model, Salapatek and Kessen[42] have shown that infants as young as eight days of age demonstrate decided eye scanning preferences. As for older children and adults, the study that led to the development of the model indicates that a prime cause is work, study and television habits and that a change in these habits will tend to alter the astigmatic status.

In turn, these scanning habits are strongly influenced by the physical nature of the environment in which one works, studies or watches television, including the lighting and the type and placement of the furniture. In addition, accommodative stress, binocular problems (including amblyopia), presbyopia, poor bilateral organization and even the mechanics involved in using a bifocal can be major factors inducing changes in eye scan habits. In fact, the relationship of both presbyopia and early myopia with the formation of against-the-rule (-cyl.×90) astigmatism appears to come about due to the "centralizing" effect that is often seen as a reaction to accommodative tension.

Regardless of the potential instigating factors, however, the change in astigmatic status appears to occur only in those who change the habitual interplay within the visual scan, head scan and head posture triad. If the visual scan habits are not changed, the astigmatic status does not appear to change.

Finally, since functional astigmatism appears to be molded by use at any age, it should be capable of being reversed to some degree by specific therapy geared to altering the relationships within the eye scan, head scan, head posture triad. A study in progress indicates that this assumption is, in fact, a valid one. Reduction in astigmatism through therapy does appear to be feasible at any age and within reasonable periods of time, regardless of the corrective prescription that is worn by the individual. The subject of therapy will be treated in greater detail in a future paper.

The major implication is that even though there may be physical or physiological causes for some types of astigmatism, the vast majority of those with astigmatism appear to have a functional variety that is caused and altered by how the eyes are used in the ongoing interaction between the individual and his environment. **AOA**

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APPENDIX

The following is an abridged outline of a suggested examiner protocol utilizing a visual imagery approach to determine how major visual tasks are performed.

I. *Patient Instructions*

1. Sit comfortably. Do not sit stiffly or push yourself all the way back in the chair. Your arms should be at your sides with your hands in your lap, at least for now.
2. Close your eyes and keep them gently closed throughout.
3. Be completely relaxed. Feel your forehead and scalp muscles relax. Feel the muscles in and around your eyes become relaxed. Feel your cheek muscles and jaw mucles totally relax. Feel your neck muscles and your shoulder muscles relax. Feel them literally go limp.
4. Listen carefully to what I say. Try to do or act out what I ask you to do. Try to picture what I ask you to picture even if what you get to see in your mind's eye is not completely clear or vivid. In fact, it may be nothing more than a vague sensation. In any case, just listen to what I say and respond as best you can.
5. Picture yourself at work on the job (or if a student, at your desk in school). With your eyes closed and your body relaxed try to shift into the position you would normally be in when you work. Try to keep a picture in your mind of the room, the desk, the things that are usually on the desk or near you, the people around you and your normal body posture as you are involved in your work. Keep your eyes closed at all times and be totally relaxed.

II. *Examiner Questions*

(The following are only suggestions. They can be varied and elaborated upon depending on the particular occupation of the patient. Throughout, watch the position of the torso, head, arms and hands. Watch for eye movements through the closed lids.)

1. You are working at your desk. Picture yourself writing something. Shift the paper to where it would normally be and start writing. Now:
   a. Look at your notes.
   b. Someone walked in. Look up.
   c. Someone near you or at your desk is talking to you. Look at the speaker.
   d. The telephone is ringing. Answer it.
   e. Look across the room to the clock (door, chalkboard, teacher, etc.).
   f. Start typing. *Look* at what you are typing. Now, look at your *notes.*
   g. Your desk work has gotten difficult. There is a problem to be worked out. It's very technical and detailed and it has to be completed very quickly. Work on it, *now.*
   h. You have a lot of things piled up on your desk. Picture where your main area of work would be in this situation. Look there and get to work now. Periodically look to where you would keep your reference papers or notes.

2. You are at home now. Picture yourself sitting in your usual seat as you do the following tasks. (With each of the following give instructions to the patient to change his gaze to something or someone else in the room that he might habitually expect to be there.)
   a. reading
   b. doing a crossword puzzle
   c. eating
   d. watching T.V.
   e. having a conversation
   f. writing a letter
   g. knitting, crocheting, needlepoint
   h. playing cards
   i. playing a board game (chess, Scrabble, Monopoly, etc.)
   j. using the telephone
   k. preparing a meal or snack

3. You are driving your car:
   a. position yourself comfortably and look at the traffic ahead.
   b. look into the rear view mirror.
   c. look into the side view mirror.
   d. talk to a passenger beside you.

4. You are walking. Picture yourself with the body and head posture you would normally have when you walk, swinging or not swinging your arms as the case may be. Now:
   a. You are coming to a curb. Look down at it.
   b. There is something shiny on the ground. Look down at it.
   c. There is something unusual in the sky (a cloud formation, a plane, etc.). Look up at it.

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