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Astigmatism as a Function of Visual Scan, Head Scan, and Head Posture

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Abstract

Contradictory views exist concerning astigmatism and its causes. Most consider it to be a structural anomaly following genetic and age patterns. Others attribute an undefined functional origin to the various forms of astigmatism. An investigation has revealed a relationship between changes in astigmatism and an observable triad consisting of eye scan, head movement, and head posture. This relationship is described and a model developed. Indications also exist that changing elements within this triad can have a positive effect in reducing astigmatism.

Key Words: astigmatism, eye scan, head scan, head posture

Ocular astigmatism is a refractive condition in which there is a variation of power in the different meridians of the eye.[1] It is a widely prevalent condition. Bannon and Walsh[2] found that over 83% of a 2000-patient sample exhibited some form of astigmatism. Astigmatism is present in infancy.[3, 4]

There appears to be a dichotomy of thought among clinical practitioners and vision researchers as to whether astigmatism is primarily an inborn structural condition that follows preprogrammed trends throughout life, or whether it is primarily a functional condition that is molded by life events and experiences. One school of thought maintains that in the absence of overt pathology, corneal astigmatism is either "congenital or an exhibition of inherited growth tendencies."[5] This is based on a number of demographical, cross-sectional, and longitudinal studies.[6-10] Grosvenor[11] from a review of these studies concludes that, as a general trend, a given individual tends to develop more with-the-rule (direct) astigmatism during the preschool years and then "less with-the-rule (or more against-the-rule) astigmatism throughout the remainder of the life span." Grosvenor also notes an accelerated shift toward more against-the-rule (inverse) astigmatism after the age of 40.[12]

Hirsch[13] points out an intriguing relationship between against-the-rule astigmatism and the future development of myopia. In the Ojai Longitudinal Study, he demon-

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strated that a number of children who became myopic in their teens exhibited against-the-rule astigmatism at age 6 when they first entered school.

Others have attributed a functional origin to astigmatism. Getman[14] views astigmatism of 1 D or less as a symptom of accommodative or convergence stress depending on the type of astigmatism. Streff and Apell[15] suggest that astigmatism results from both visual-spatial searching as well as being a visual reaction to stress. They specifically perceive the against-the-rule astigmat as having trouble changing focus from near to far. Birnbaum[16] hypothesizes that against-the-rule astigmatism develops as an early form of adaptation to accommodative stress. Harmon[17, 18] suggested a relationship between posture and the development of astigmatism. Childress et al.,[19] taking the reverse approach, demonstrated that low degrees of astigmatism could be used to predict postural habits as they relate to occupational demands. They grouped 69 patients by occupation, investigated the visual demands of each group, and performed a complete visual analysis of each patient. Their results indicated that: (1) with-the-rule astigmatism appeared to relate to side-to-side viewing demands; (2) against-the-rule astigmia appeared to relate to up-and-down viewing demands; (3) oblique astigmia appeared to relate to an oblique viewing demand; and (4) the eye with the greater astigmia was usually kept further away from the fixation point.

My involvement was initiated by three clinical observations. The first was the occurrence of unpredictable and apparently unaccountable changes in the magnitude, type, and axis of the astigmatism that occurred in some clinical patients within a period of 1 year or less. The second was that, contrary to reported statistical trends, many incipient myopes, presbyopes, and those with signs of accommodative stress did not demonstrate either a reduction of with-the-rule astigmatism or an increase in against-the-rule astigmatism. The third was the sudden and dramatic decrease in the long-standing and stable binocular astigmatism of a 43-year-old female patient from −6.00 axis 90 to −1.25 axis 90 as an apparent result of being placed in skeletal traction and being kept horizontal most of each day (through the use of special orthopedic tongs attached to each side of her skull) for a period of almost 8 weeks. Not only was there a radically enforced change in body posture in relation to gravity but, unlike most bedridden patients, her head was immobilized and the most comfortable eye movement in that situation was a side-to-side scan. The fact that this radical change in astigmatism could occur in a mature individual suggested that, under specific conditions, the visual system, at least in respect to astigmatism, might be sufficiently plastic in nature to be capable of alteration regardless of age.

It was this change that became the basis for the clinical investigation. For a period of over 4 years, hundreds of patients who demonstrated changes in their astigmatic status were questioned to determine if there were precipitating causes that could be related to the changes. Others with stable astigmia were questioned to determine if specific factors could be related to specific types of astigmatism. The patients were asked to describe the type of prolonged visual tasks they performed and how they did them, how they sat, how they held their heads, how their work was placed, and how they changed their fixation in the usual course of their work. Television, kitchen, workshop, and sports habits were probed. In many instances, patients were asked to act out or demonstrate at the desk how they performed at work or school. In other instances, parents or spouses were asked to describe the visual, postural, television, work, and study habits of the patient. In still other instances, the patients were asked to close their eyes and visualize themselves working and then respond to specific questions such as "look up from your work," "answer the desk phone," "start typing," all depending on the particular job they did.

Relationships were revealed that seemed to indicate that most astigmatism, regardless of magnitude, was functionally related to visual task habits and that it developed or changed in a consistent manner. The

pattern that was revealed also helped explain why certain trends were seen at certain age levels in some subjects and not in others.

Based on this investigation, a working hypothesis was formulated that related the development of functional astigmatism to a triad consisting of eye scan, head scan, and head posture. Eye scan refers to eye movement free of accompanying head movement. Head scan refers to an eye movement that is yoked to a head movement. Head posture refers to a combination of the angle (vertical positioning), rotation, and tilt of the head in relation to gravity onto which the eye/head movement is superimposed.

One principle that appears to be behind the interrelationship among these three factors pertains to freedom of movement. The eyes and the head have the potential to be yoked together or to move in many possible combinations in relation to each other. Persistent selective limitation of any of these potential movements on a meridional basis appears to be the cause of a structural adaptation that leads to the development of astigmatism. For example, if one regularly tends to move the eyes more than the head when scanning in one meridian and tends to move the head more than the eyes when scanning in the meridian 90° away, an astigmatism will tend to develop with the minus cylinder axis in the meridian of greatest "eye" scan. Viewing it another way, the refractive surfaces of the eye tend to become toroidal, creating an astigmia that has the strongest power in the meridian of greatest "head" scan, where eye and head movement tend to be yoked together. It is as if the response of the visual system to a limitation of movement in one meridian produces a tendency to become myopic (or less hyperopic) in that meridian. The following are key elements that were found: (1) With-the-rule (minus cylinder axis 180) astigmatism appears to relate to a greater preference for "eye" scanning in the horizontal meridian. (2) Against-the-rule (minus cylinder axis 90) astigmatism appears to relate to a greater preference for "eye" scanning in the vertical meridian.

The magnitude of the astigmatism was found to relate to the difference in scanning mode between the eye scan and head scan meridians. The more persistent the eye scan is in one meridian as related to the head scan in the opposing principal meridian, the greater will be the magnitude of the astigmatism. Astigmatism of 0.5 D indicates less visual scan free of head movement in the eye scanning meridian than does 2 D of astigmatism. In other words, the greater the amount of astigmatism the less head movement is used in the minus cylinder axis meridian as opposed to the meridian 90° away.

Interestingly, little or no astigmatism seems to develop when eye/head scan preferences are approximately equal in all meridians.

In cases where there is a difference in the magnitude of astigmatism between the two eyes (astigmatic anisometropia), the eye with the greater astigmatism tends to be the one that views the task by peering across the midline of the face. A difference in astigmatic power between the two eyes seems to result from a 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. The greater the angle formed between where the eyes and nose point, the greater will be the astigmatism in the eye that peers across the nose and therefore, the greater will be the anisometropic difference in the astigmatism.

This situation can occur in a few ways. First, if the visual task (e.g., writing) is decentered to the right or left of the body midline without the head being fully rotated to center on it. Second, if the head is rotated away from the task even though the task itself is directly before the subject. Third, a combination of both.

The position of the eye closest to the task seems to determine how much relative astigmatism each eye has. If the task is directly in front of the right eye while the head is rotated to the left, the left eye would be expected to show a moderate astigmia (e.g., −2.25 D) while the right eye might exhibit little or no astigmatism.

Parallel oblique astigmatism is a condition in which the axes of astigmatism are approximately the same in both eyes, both being oblique. This appears to be related to a consistent obliquity in visual scanning

that is associated with a tilted position of the task, the head, or both. The obliquity of the axis bears a direct relationship to the angle formed by the position of the "horizontal" plane of the eyes and the plane of preferred visual scanning. The greater the angle, the greater will be the obliquity. If, however, the tilted position of the horizontal plane of the eyes exactly matches the oblique position of the task so that the angle formed is zero, the resultant astigmatism tends to be with-the-rule regardless of the head tilt. If the tilted position of the horizontal plane of the eyes forms a 90° angle with the plane of preferred visual scan, the resultant astigmatism tends to be against-the-rule. If the visual scan is consistent in all meridians, no astigmatism appears to develop regardless of the persistent angling of the head or of the task.

Symmetrical oblique astigmatism is a condition in which the axes of astigmatism of the two eyes are extorted or intorted, more or less symmetrically, from the vertical. It seems to involve a number of causative factors that include an interrelationship among the frontal plane of the head, the primary position plane, the plane of regard, and the preferred scan.

Operationally, the primary position plane can be considered as a plane at the level of the two eyes that is perpendicular to the front (or facial) plane of the head. The plane of regard can be considered as a plane connecting the lines of sight of the two eyes as they fixate the object of regard. Symmetrical oblique astigmatism appears to arise from a consistent disparity between head position and the slope of the habitually scanned fixation target(s).

As a general rule, persistent scanning above the operational primary position plane tends to result in intorted symmetrically oblique axes. This appears to be the general response in binocular subjects. Nonbinocular subjects have been noted to reveal the reverse obliquity. The binocular vertical scanner tends to demonstrate intorted axes closer to the vertical. The horizontal eye scanner tends to demonstrate intorted axes closer to the horizontal. The further the average scan is above the primary position plane, the closer the axes approach OD axis 45, OS axis 135.

Those binocular subjects who scan consistently below the operational primary position plane tend to reveal extorted symmetrically oblique axes. The predominantly vertical scanners tend to reveal extorted axes closer to the vertical while the horizontal scanners exhibit axes closer to the horizontal. The further below the average scan is from the primary position plane, the closer the axes approach OD axis 135, OS axis 45. As an added observation, it also appears that the "chin down" (above primary position plane) scanners do not have to scan as much above the operational primary position plane to achieve the axes OD 45, OS 135 obliquity as the "chin up" (below primary position plane) scanners have to look below the operational primary position plane to achieve the axes 135 OD, OS 45.

Even though it is not the purpose of this paper to pursue the possible physiological correlates that might match the clinical observations being described, it should be noted that the factors involved in the formation of oblique astigmatism seem to be quite consistent with the compensations that are necessary to overcome the torsional elements involved in extraocular muscle action. This relationship will be elaborated upon in a future paper.

Asymmetrical astigmatism (where the axes of astigmatism are neither parallel nor totally symmetrical) seems to be due mainly to an oblique scanning preference or a head tilt superimposed onto an angled head/task relationship. In most instances, a head tilt to one side tends to relate to a more oblique axis of astigmatism in the eye on that same side.

The extreme of asymmetry is found in perpendicularly opposing astigmatism (e.g., OD − cyl. axis 90; OS − cyl. axis 180). The majority of cases with this type of astigmatism appear to have some form of binocular fusional problem and the type of scan tends to relate to what is done on the right and left sides of the midline. A 22-year-old, male welder, for example, was found to tilt and rotate his head to the left when working up and to the right so that, in effect, his visual scan was horizontal on the right side. When working to the upper left, he tended to keep his head relatively straight while scanning vertically and sighting with the left eye. The resultant astig-

matism was OD − cyl. axis 180; OS − cyl. axis 90. Another patient, a 45-year-old male, with against-the-rule astigmatism in the right eye and with-the-rule astigmatism in the left eye, was found to be an eye mover whenever he had to look toward the left and a head mover when gazing to the right. In addition, when looking up and to the right he was predominantly an eye scanner while reverting to being mainly a head scanner when gazing up and to the left. Both of these patients exhibited significant binocular difficulties.

TESTING THE HYPOTHESIS

When these relationships were recognized, it was decided to test the hypothesis in a more formal manner. A clinical study was organized using consecutively seen patients that met the following criteria:

1. The key element in the study was a change in the astigmatic status. The change could be in the magnitude or the axis of the astigmatism.
2. The minimum magnitude of change had to be at least 0.50 D except where a significant shift in axis was concerned.
3. The previous visual examination must have been between 6 to 18 months prior to the current visit.
4. The author had to have taken all measurements. This was to ensure consistency.
5. All patients were to be between 20 and 40 years old. Twenty years of age was decided upon to assure that the visual system and ocular status were mature, structured, and free of the statistically noted relationship between against-the-rule astigmatism and incipient myopia. The cutoff point of 40 years of age was decided upon to avoid the major changes associated with presbyopia. It was assumed that if changes in astigmatism could be demonstrated within this age group, they might be more clearly related to specific changes in eye usage rather than to growth or age factors.
6. Even though both subjective and objective measurements were made on all patients, the final reference was always to the astigmatism found under subjective testing.

A total of 45 patients were studied. This included 10 patients whose astigmatism increased in a with-the-rule direction in both eyes, 10 patients whose astigmatism increased in an against-the-rule direction in both eyes, 5 patients whose axis changed in an oblique direction toward axis 135 in the right eye and/or toward axis 45 in the left, 5 patients whose axis changed in an oblique direction toward axis 45 in the right eye and/or axis 135 in the left, 5 patients whose astigmatism changed 0.50 D or more and more in the right eye then in the left, 5 patients whose astigmatism changed 0.50 D or more and more in the left eye than in the right, and 5 patients whose axes changed toward perpendicularly opposing axes (vertical in one eye and horizontal in the other). Even though some overlap occurred, the major direction of change of the astigmatism determined into which group the patient was placed.

Each of these patients was extensively questioned to determine whether there were any recent changes in either their job, work habits, or home environment, especially those related to prolonged and concentrated visual tasks. In almost every case some change was reported to have taken place in the manner in which major visual work was done. The change in each instance was related to some alteration in eye scan/head scan/head posture usage. In addition, the environmental change or change in work habits was found to have occurred within 4 to 12 months of the current examination (see Appendix I).

Since the results of this study were supportive of the hypothesis, it was decided that one should be able to predict the habitual eye scan/head scan/head posture relationship during major visual performance tasks from the astigmatic component of the refractive findings. To do this, a second clinical study was initiated. For this study 50 consecutive patients were selected, the only requirement being that some degree of astigmatism was present. No change in astigmatic status was required. The distribution by age was as follows: 5 years and younger (3); ages 6 to 12 (16); ages 13 to 20 (11); ages 21 to 30 (10); ages 31 to 40 (4); and age 41 and over (6).

No questions regarding eye use were directed to the patients (or parents). After the examination a "prediction" was made as to what the patient's typical eye scan/head scan/head posture relationship was when doing major visual tasks. Exactly 41

patients (or parents) confirmed the accuracy of the predictions; 7 patients (14%) were unsure of their visual habits; 2 patients (4%) challenged the accuracy of the predictions (see Appendix II).

Probably some subjects accept what is told them by an authority figure. This would tend to dilute the accuracy of the predictions. However, if we add some of the 14% who were unsure of their visual habits but did not reject the predictions to the group who confirmed their accuracy, then even if some responses cannot be accepted as valid the overall total still remains fairly high.

Many patients in the first study had the minimum amount of change in the magnitude of astigmatism that was acceptable (0.5 D) for inclusion in the study. The fact that the direction of these changes was consistent with the changes in work or study habits indicates that the trend itself is significant even if the magnitude of change is small. The second study which includes smaller amounts of astigmatism seems to reinforce this conclusion.

Some patients who were seen outside of the study format revealed even more dramatic results. One adult female patient, for example, showed an increasing with-the-rule astigmia with the development of a bilateral ptosis. A young man, on the other hand, given the opportunity to become a professional basketball player started actively practicing free throws into the basket for hours every day. Within 3 months he developed 0.75 D against-the-rule astigmatism.

Keratometric data have not been included in these studies since they did not demonstrate the same consistency with changes in eye usage as did measurements of total ocular astigmatism.

DISCUSSION

This investigation indicates that even though there may be physical or physiological causes for some types of astigmatism, many subjects appear to exhibit a functional variety that is caused and altered by use. A major element in this usage involves the basic interrelationship among the factors of eye scan, head scan, and head posture. Preferences for greater eye movement free of head movement in one principal meridian over another are found at all ages. Salapatek and Kessen[20] have shown that infants as young as 8 days of age demonstrate eye scanning preferences.

Presbyopia and intense near visual stress may produce tension in the accommodative system but it appears that only those who respond to the stress by altering their work habits, limiting their horizontal eye scan, and developing a greater eye scan in the vertical meridian will develop against-the-rule astigmatism. Therefore, regardless of the instigating cause, be it accommodative stress, presbyopia, poor bilateral organization, the mechanics of using a bifocal, convergence difficulty, etc., a change in astigmatic status appears to occur in those who change the interplay between visual scan, head scan, and head posture.

This investigation also revealed possible insights into the relation of contact lens wear and induced astigmatism. Two hard contact lens patients who developed with-the-rule astigmatism pointed out that discomfort in looking upward while wearing the lenses resulted in their becoming head movers for upward gazing and eye movers for lateral looking. A soft contact lens patient who developed against-the-rule astigmatism had a problem caused by his lenses decentering on lateral gaze (due to narrow and tight temporal lid angles). To compensate, he became a head mover horizontally and an eye scanner vertically.

Finally, since astigmatism appears to be capable of change at any age in association with alterations in eye usage, it is possible that astigmatism could be minimized by a directed change of the relationships within the triad. A study in progress indicates that this is, in fact, a valid assumption. As an example, a 17-year-old, following a prescribed regimen was able to change his refractive status from OD -3.00 -1.50×180, OS -3.75 -0.25×5 to OD -3.00 -0.50×180, OS -4.00 sphere within a 4-month period. The subject of therapy will be treated in greater detail in a future paper.

Astigmatism, it is suggested, is one way in which eye structure comes to terms with functional environmental demands. The most important implication is that structure which is moldable by use is also potentially capable of being altered by therapy

once insight is gained into the interplay of forces that are involved in the process.

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APPENDIX I

Relating Short-term Astigmatic Changes to Changes in Eye Usage

Increased with-the-Rule

Age	Sex	Examination 1	Examination 2	Interval between Examinations	Patient Reports
23	M	OD −2.25 Sph OS −2.00 Sph	OD −2.25 −0.25 × 180 OS −1.75 −0.75 × 180	12 mos	Student; moved to new apartment 7 mos ago; studies now sprawled on the bed; work spread out sideways, mostly to right; immobilizes head by resting it on left hand while scanning visually from side to side.
20	M	OD −3.00 Sph OS −3.00 Sph	OD −3.00 −0.75 × 180 OS −2.75 −0.75 × 180	7 mos	Started working 6 mos before; uses a computer most of the day; scans visually horizontally; looks up with head.
31	F	OD +0.75 −0.50 × 170 OS +1.00 −0.25 × 180	OD +0.75 −0.75 × 170 OS +1.00 −0.75 × 180	12 mos	Was a typist until 4 mos ago (kept copy on left side); now an Executive Secretary; work is more spread out; predominantly an eye scanner horizontally; raises head when looking up.
28	F	OD −2.00 −1.00 × 10 OS −2.50 −1.25 × 175	OD −2.25 −1.50 × 10 OS −2.75 −1.75 × 175	12 mos	Graduated college 6 mos ago; now working as a draftsman; does more side-to-side scanning now; keeps head to left side of her work.
40	M	OD −0.50 −0.25 × 180 OS −0.50 −0.25 × 180	OD −0.50 −0.50 × 180 OS −0.50 −0.75 × 180	14 mos	Engineer; started working with a computer approximately 8 mos ago; computer is to right of where he works; does more horizontal eye scanning.
22	F	OD +0.25 −0.25 × 180 OS +0.25 −0.25 × 180	OD +0.50 −0.50 × 180 OS +0.50 −0.75 × 180	12 mos	Graduated college 5 mos ago; now works in a bank with more side-to-side viewing required; postures head to left of her work.
30	M	OD −3.25 −0.50 × 180 OS −3.50 −0.50 × 180	OD −3.75 −1.00 × 180 OS −4.00 −1.00 × 175	13 mos	Was promoted 7 mos ago; doing much more paper work which is now spread out over his desk; scans more with eyes horizontally than before; tends to raise head when looking up.

Age	Sex	Examination 1	Examination 2	Interval between Examinations	Patient Reports
36	F	OD Plano −0.25 × 180 OS +0.25 −0.50 × 5	OD +0.25 −0.50 × 180 OS +0.50 −1.00 × 180	12 mos	Was a housewife until 5 mos ago; now works full time as a department store clerk; scans visually over a large horizontal area, tends to view more to the right side without rotating head.
24	F	OD −3.00 −0.75 × 180 OS −3.25 −0.75 × 180	OD −3.00 −1.25 × 180 OS −3.25 −1.25 × 3	12 mos	Recent graduate; got clerical job 8 mos ago; doing much desk work, spread out; scans with eyes horizontally and with head vertically.
31	M	OD +0.25 −0.25 × 90 OS Plano −0.25 × 90	OD +0.25 −0.25 × 180 OS +0.25 −0.25 × 180	11 mos	Was a salesman (writing orders while scanning with eyes when looking up); now has a desk job (for past 5–6 mos); works to both sides; does more horizontal eye scanning.
			Increased Against-the-Rule		
22	M	OD +0.75 Sph OS +0.75 Sph	OD +0.25 −0.50 × 90 OS +0.25 −0.50 × 90	13 mos	Recently entered graduate school; changed work habits about 6 mos ago; works on a narrow desk with work and book stand directly in front of him; has been doing more vertical eye scanning.
40	M	OD −2.25 −3.25 × 86 OS −2.25 −3.25 × 90	OD −1.75 −4.00 × 86 OS −1.75 −3.75 × 90	12 mos	Administrator; started to do more centralized close work; volunteers that he is a vertical eye mover (a "peerer") and moves his head to look horizontally; feels he is doing more of this lately.
28	F	OD Plano −1.00 × 90 OS Plano −0.75 × 85	OD Plano −1.50 × 90 OS Plano −1.25 × 85	14 mos	Started taking lessons in oil painting 7 mos ago; uses easel and works with models; scans with eyes vertically; uses head movement when looking to the side.
23	M	OD +0.50 −0.25 × 90 OS +0.50 −0.25 × 90	OD +0.50 −0.75 × 90 OS +0.50 −0.50 × 90	13 mos	Started working as a bank teller 5 mos ago in a small booth; does much more vertical eye scanning.

Age	Sex	Examination 1	Examination 2	Interval between Examinations	Patient Reports
37	F	OD +0.25 −0.50 × 80 OS +0.25 −0.25 × 95	OD Plano −0.75 × 80 OS Plano −0.75 × 95	12 mos	Started a new office job (receptionist) 4 mos ago, most of her desk work is directly in front of her; does greater vertical eye scanning looking up at those who stop at her desk.
30	M	OD Plano OS Plano −0.25 × 180	OD +0.25 −0.50 × 90 OS Plano −0.25 × 90	13 mos	Police officer; started intense studying 4–5 mos ago for promotion; keeps work directly before him and not to sides; glances up more with eyes; when looking to sides he moves his head.
24	F	OD −1.00 −0.25 × 90 OS −1.25 −0.50 × 90	OD −1.25 −0.75 × 90 OS −1.50 −1.00 × 90	12 mos	Started studying to be a dental technician approximately 10 mos ago; has been doing more close work and due to the type of work has become more of an eye scanner vertically.
32	M	OD +0.50 Sph OS +0.75 −0.25 × 90	OD +0.50 −0.50 × 90 OS +0.75 −0.75 × 90	12 mos	Started working with a computer terminal placed directly before him 6–7 mos ago; scans more with eyes vertically.
39	M	OD −0.25 −0.25 × 180 OS −0.25 Sph	OS Plano −0.25 × 90 OS Plano −0.50 × 90	14 mos	Was promoted to plant supervisor 9 mos ago; does less desk work; carries a clip board and moves around factory glancing up and down as he writes.
40	F	OD +0.25 Sph OS +0.25 Sph	OD +0.50 −0.50 × 90 OS +0.25 −0.25 × 90	12 mos	Worked as general office supervisor until 5 mos ago; now retired; spends hours each day doing needlepoint and glancing up at television without moving head.
		Increased Anisometropia (OS > OD)			
24	M	OD −2.25 −0.50 × 90 OS −1.25 −0.50 × 85	OD −2.50 −0.50 × 90 OS −1.75 −1.00 × 90	13 mos	Started working on IBM retrieval system 8 mos ago; machine up and to the right; keeps head forward and peers to right.

Age	Sex	Examination 1	Examination 2	Interval between Examinations	Patient Reports
26	F	OD −6.25 −0.25 × 180 OS −4.75 −1.00 × 180	OD −6.75 Sph OS −5.00 −1.75 × 180	13 mos	Was a clerk; got a desk job 7 mos ago; rotates head to left when working; OD in line with desk work; OS peers across nose.
38	M	OD +0.50 −0.50 × 90 OS +0.50 −0.25 × 90	OD +0.50 −0.25 × 90 OS +0.50 −0.75 × 90	12 mos	Stockbroker; 4 mos ago was given a new desk with video terminal on the right side; works directly in front of him but peers continually at terminal without rotating head.
34	F	OD −2.00 −1.25 × 80 OS −2.50 −1.25 × 100	OD −2.00 −0.75 × 80 OS −2.50 −1.50 × 100	14 mos	Housewife; redecorated house 5 mos ago; watches much television; the televisions (in kitchen, den, and bedroom) are all placed to the right of where she positions her head.
39	F	OD −1.50 −0.25 × 15 OS −1.50 −0.25 × 165	OD −1.50 −0.25 × 15 OS −1.75 −0.75 × 165	13 mos	Interviewer; position of desk changed approximately 6 mos ago; applicants sit to her right; she writes with work directly before her; gazes to right.
		Increased Anisometropia (OD > OS)			
24	F	OD −2.00 −0.50 × 90 OS −2.00 −0.50 × 90	OD −1.75 −1.00 × 90 OS −2.00 −0.50 × 90	11 mos	Designer; for past 6 mos; does artwork squatting while peering to the left side.
31	M	OD −0.25 Sph OS +0.25 −0.25 × 180	OD Plano −0.50 × 180 OS Plano Sph	12 mos	Office worker; is left handed and keeps work to left with head rotated to the right; scans more to the left from this position since being given a corner desk 5 mos ago.
40	M	OD −1.00 −0.25 × 170 OS −1.00 −0.25 × 180	OD −1.00 −0.75 × 170 OS −1.00 −0.25 × 180	11 mos	Office manager; started a new hobby 6 mos ago involving extensive detailed model building; has been rotating his head to the right when doing this work; (patient is left handed and has a preferred left sighting eye).
22	F	OD +0.50 −1.00 × 180 OS +0.50 −1.00 × 165	OD +0.75 −150 × 180 OS +0.50 −0.75 × 170	12 mos	Started working with a computer approximately 5 mos ago; computer is on the left side; paper work is in front; peers at computer without rotating head.

Age	Sex	Examination 1	Examination 2	Interval between Examinations	Patient Reports
36	F	OD −1.00 Sph OS −1.25 −0.25 × 180	OD −1.00 −0.50 × 180 OS −1.00 Sph	14 mos	Changed jobs 11 mos ago; doing more clerical work than before; keeps work on left side (left hander); head is kept straight ahead in order to look up at customers and salesmen.
		Increased Axis Obliquity (Extorted)			
39	F	OD −0.50 −0.75 × 165 OS −0.50 −0.50 × 10	OD −0.50 −0.75 × 165 OS −0.50 −0.50 × 40	13 mos	For past 4–5 mos has started to do a lot of reading in bed; keeps chin up; sights down; tilts head to left.
20	F	OD +1.00 −0.50 × 165 OS Plano −0.25 × 15	OD +1.00 −0.50 × 140 OS Plano −0.25 × 30	13 mos	Has new desk job for past 6 mos; tends to keep head high; sights low; scans horizontally.
40	M	OD +2.00 −0.25 × 90 OS +2.25 −0.25 × 90	OD +2.50 −0.25 × 120 OS +2.50 −0.50 × 70	12 mos	Doing more concentrated desk work for past 9 mos; keeps work low in relation to head position; scans vertically.
23	M	OD Plano −0.75 × 90 OS Plano −0.75 × 80	OD Plano −0.75 × 95 OS Plano −0.75 × 70	12 mos	Accountant; was given a new office in a different location 7 mos ago; keeps work close to body; sights low; scans vertically; tilts head to left.
21	M	OD −2.00 −0.50 × 105 OS −2.00 −0.50 × 70	OD −2.50 −1.00 × 115 OS −2.50 −0.75 × 60	14 mos	Studying engineering; has been doing a lot of drafting for past 8 mos; peers downward with chin up.
		Increased Axis Obliquity (Intorted)			
39	F	OD −3.25 −0.25 × 75 OS −3.00 −0.50 × 105	OD −3.00 −0.25 × 55 OS −3.00 −0.50 × 120	13 mos	Became a department store clerk 8 mos ago; keeps head down; sights high.
40	F	OD Plano Sph OS Plano −0.25 × 150	OD −0.50 −0.25 × 45 OS Plano − 0.75 × 135	11 mos	Became a switchboard operator 8 mos ago; keeps head relatively low; sights high.
36	F	OD −1.50 −0.25 × 180 OS −1.50 −0.50 × 170	OD −1.75 −0.25 × 10 OS −1.50 −0.50 × 150	15 mos	Has new office job for past 5 mos; sits erect with chin held low; works away from body; sights high; horizontal scanner.

Age	Sex	Examination 1	Examination 2	Interval between Examinations	Patient Reports
27	M	OD +0.25 −0.50 × 85 OS +0.50 −0.50 × 90	OD +0.25 −0.50 × 70 OS +0.50 −0.50 × 95	12 mos	Working with a computer for past 7 mos; chin down; sights high; scan is predominantly vertical.
21	M	OD +0.50 −0.25 × 80 OS +0.50 −0.25 × 100	OD +0.50 −0.25 × 60 OS +0.50 −0.25 × 115	13 mos	Took job as a rail inspector 4 mos ago; keeps chin down; scan is relatively vertical.
		Change Toward Perpendicularly Opposing Axes			
27	M	OD −0.50 −0.50 × 165 OS −0.75 −0.25 × 60	OD −0.75 −0.50 × 180 OS −0.75 −0.50 × 85	12 mos	Started to work as an automobile welder 9 mos ago; moves eyes when looking to the right; rotates head when working to the left; remote NPC; limited vergence breaks and recoveries; right hand-right eye preference.
38	M	OD −2.00 Sph OS −2.00 −0.25 × 90	OD −2.00 −0.25 × 180 OS −2.00 −0.50 × 90	14 mos	Became a cleaning store owner and operator 8 mos ago; he and wife notice that lately he has been looking to the right with his eyes but tends to turn his head in order to look to the left; low vergences; right hand-right eye preference.
36	M	OD + 0.25 Sph OS +0.25 Sph	OD +0.25 −0.50 × 95 OS +0.25 −0.50 × 170	12 mos	Changed jobs 10 mos ago; works in a book store; papers kept to the left; reference books on shelves to the upper right (scans horizontally to left and vertically to the right); has developed a convergence insufficiency within this past year.
22	F	OD + 0.50 Sph OS +0.50 −0.25 × 180	OD +0.50 −0.50 × 90 OS +0.75 −0.50 × 180	12 mos	Doing more close work in the past year (especially within past 9 mos): had history of convergence insufficiency which has gotten worse; does more vertical eye scanning on the right side and horizontal on the left.

Age	Sex	Examination 1	Examination 2	Interval between Examinations	Patient Reports
20	M	OD −3.50 Sph OS −3.75 Sph	OD −3.75 −0.25 × 75 OS −4.00 × 0.25 × 165	12 mos	Doing more studying in prone position on a bed; papers spread out so that he scans vertically on the right side and horizontally on the left: binocular findings poorer with low vergence breaks and recoveries.

APPENDIX II

Predicting Scanning Status from Astigmatic Status

Note:

1. The study population (N = 50) is listed by age.
2. The predictions were made solely on the basis of the astigmatic status and not the sign or magnitude of the spherical component.
3. The notes listed under the "prediction" column are simply the key elements of what was described to the patients.
4. The code used for the patient (or parent) response is: a. agreement (+); b. disagreement (−); and c. unsure. (?)

Age	Sex	Astigmatic Status	Prediction	Patient (or Parent) Response
3	F	+1.00 −0.50 × 75 +0.50 −1.00 × 105	Vertical eye scan preference; holds work to right of facial midline; scans in relative "chin down/eyes up" position.	+
3	M	+0.75 −0.75 × 90 +0.75 −0.50 × 90	Vertical eye scan preference; holds work (or sights) slightly to left of facial midline.	+
5	F	+0.50 −0.50 × 180 +0.50 −0.50 × 180	Horizontal eye scan preference.	?
6	F	+0.75 −0.25 × 180 +1.00 −1.00 × 180	Horizontal eye scan preference; rotates head to left when doing visual tasks.	+
7	M	+2.25 −1.75 × 135 Plano −2.00 × 60	Vertical eye scan preference; works in a relative "chin up/eyes down" position.	+
7	M	−0.25 Sph Plano −0.25 × 90	Slight vertical eye scan preference; works with slight head rotation to left.	?
8	F	−0.25 −0.25 × 135 −0.25 −0.25 × 45	Slight horizontal eye scan preference; works in a "chin up/eyes down" posture.	−
8	M	+0.25 −0.25 × 90 −0.50 −0.50 × 90	Vertical eye scan preference; sights slightly to right of facial midline.	+
8	F	+2.50 −0.50 × 90 +2.50 −1.00 × 180	Vertical eye scan preference when looking right; horizontal eye scan preference when looking left; tends to keep work to right of facial midline.	+
8	M	Plano −0.75 × 90 Plano −0.75 × 90	Vertical eye scan preference.	+
9	F	−1.00 −0.50 × 180 −1.00 Sph	Horizontal eye scan preference; tends to rotate head to right; works directly in front of left eye.	+
10	M	−0.50 −0.25 × 100 −0.25 −0.75 × 80	Vertical eye scan preference; works to right of facial midline; works in a relative "chin up/eyes down" posture.	+
10	F	+0.50 −0.50 × 90 +1.00 −0.75 × 90	Vertical eye scan preference; tends to work to right of facial midline.	+
10	F	+3.00 −0.75 × 75 +2.75 −1.50 × 100	Vertical eye scan preference; works to right of facial midline; works in a relative "chin down/eyes up" posture.	+
11	M	+0.25 −0.50 × 90 Plano −0.75 × 90	Vertical eye scan preference; works slightly to right of facial midline.	+
12	M	+0.50 −0.50 × 105 +0.50 −0.50 × 75	Vertical eye scan preference; works in a relative "chin up/eyes down" posture.	+
12	F	+0.75 −0.25 × 60 +0.50 −0.25 × 60	Oblique eye scan preference (upper left to lower right).	?
12	F	+0.25 −0.50 × 75 −0.25 −0.25 × 95	Vertical eye scan preference; works slightly to left of facial midline; works in a slight "chin down/eyes up" posture with slight head tilt to right.	+
12	F	−3.00 −1.50 × 180 −3.50 Sph	Horizontal eye scan preference; works with left eye in line with visual task and head rotated to right.	+

Age	Sex	Astigmatic Status	Prediction	Patient (or Parent) Response
13	M	−5.50 −0.75 × 95 −4.75 −0.25 × 90	Vertical eye scan preference; works slightly to left of facial midline with a head rotation to right.	+
13	M	+1.00 −0.25 × 180 +1.00 −0.25 × 180	Slight horizontal eye scan preference.	?
14	M	−1.00 −0.50 × 150 −1.00 −0.50 × 60	Works in a "chin up/eyes down" posture with head tilted to the right.	+
15	M	−0.25 −0.50 × 75 −0.25 −0.75 × 105	Vertical eye scan preference; works slightly right of facial midline; works in a relative "chin down/eyes up" posture.	+
15	M	−1.75 −0.25 × 90 −1.75 −0.25 × 90	Slight vertical eye scan preference.	+
17	F	−3.50 −0.75 × 90 −3.25 −0.75 × 90	Vertical eye scan preference.	+
17	F	+0.75 −0.50 × 180 +1.00 −0.50 × 180	Horizontal eye scan preference.	+
19	F	+0.50 −1.00 × 85 +0.75 −1.00 × 95	Vertical eye scan preference.	+
19	M	−3.25 −1.50 × 178 −4.00 −1.25 × 165	Horizontal eye scan preference; works slightly to left of facial midline.	+
19	F	−0.25 Sph +0.25 −0.75 × 165	Work kept directly in front of right eye; rotates head to left; horizontal eye scan preference.	+
20	F	−5.00 −0.25 × 180 −4.50 −0.75 × 180	Horizontal eye scan preference; works slightly to right of facial midline possibly with a slight head rotation to the left.	?
21	M	+1.00 −1.50 × 180 +1.00 Sph	Horizontal eye scan preference; work kept directly in front of left eye; head rotated to right.	+
21	M	−0.75 −0.50 × 90 −0.75 −0.25 × 90	Vertical eye scan preference; works slightly to left of facial midline.	+
22	F	+1.00 −1.50 × 30 +1.25 −1.00 × 135	Works in a "chin down/eyes up" posture; work kept to left of facial midline.	+
22	M	+2.50 −1.00 × 180 +2.50 −1.50 × 180	Horizontal eye scan preference; works to right of facial midline.	+
23	F	−0.75 −0.75 × 20 −1.25 −0.25 × 15	Works to left of facial midline possibly with a slight head rotation to the right; scan is predominantly horizontal angled slightly up and to the left.	+
24	F	−1.00 −0.25 × 105 +0.50 −0.75 × 15	Right eye generally kept in line with task with head rotated to left; vertical eye scan preference on the right side; horizontal eye scan preference on the left.	+
26	M	−0.25 −0.75 × 165 Plano −0.25 × 180	Horizontal eye scan preference; works slightly to left of facial midline with a head rotation to the right.	+
28	F	+3.00 −1.25 × 110 +3.00 −1.25 × 72	Vertical eye scan preference; works in a "chin up/eyes down" posture.	+
29	F	+0.50 −0.50 × 90 +0.75 −0.50 × 180	Vertical eye scan preference for right side; horizontal eye scan preference for left side.	?
30	F	−3.75 −1.25 × 100 −3.75 −0.50 × 80	Vertical eye scan preference; works in slight "chin up/eyes down" posture.	+
32	M	Plano −0.25 × 180 −0.25 −0.50 × 180	Horizontal eye scan preference; works slightly to right of facial midline.	+
36	M	−0.50 −1.50 × 180 −1.00 −1.00 × 170	Horizontal eye scan preference; works to left of facial midline.	+
39	F	+0.25 −0.25 × 180 +0.25 −0.75 × 180	Horizontal eye scan preference; works to right of facial midline possibly with a slight head rotation to the left.	+

Age	Sex	Astigmatic Status	Prediction	Patient (or Parent) Response
40	F	+1.50 −0.50 × 165 +1.00 Sph	Horizontal eye scan preference; work kept directly in front of left eye; head rotated to right.	+
42	M	−1.25 −1.50 × 170 −1.25 −0.75 × 95	Horizontal eye scan preference for the right side; vertical eye scan preference for the left side; work generally kept to left of the facial midline.	+
49	F	+1.50 −1.75 × 20 +1.00 −2.25 × 165	Horizontal eye scan preference; work kept to right side of facial midline; works in "chin down/eyes up" posture.	+
51	F	+4.50 −1.25 × 25 +5.25 −0.75 × 135	Horizontal eye scan preference; work kept to left side of facial midline; works in "chin down/eyes up" posture.	−
53	F	+0.50 −1.75 × 90 +0.75 −1.75 × 80	Vertical eye scan preference.	+
55	F	+1.00 −0.50 × 60 +0.50 −0.25 × 60	Oblique eye scan preference (upper left to lower right); works slightly to left of the facial midline.	?
62	M	Plano −0.25 × 180 −0.25 −0.50 × 180	Horizontal eye scan preference; work kept slightly to right of facial midline.	+