ARTICLE

The Shape of the Sky: The Art of Using Egocentric Stereopsis in the Treatment of Strabismus

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ABSTRACT

A protocol for using stereopsis in the treatment of strabismus is described. Suitable for patients with either normal retinal correspondence (NRC) or anomalous binocular correspondence (ABC), the approach emphasizes the interactions between peripheral/egocentric and central/relative stereopsis in such dichoptic instrumentation as vectograms, digital instrumentation, and 3D movies. The paper then discusses the transfer of appreciation of stereopsis from such artificial dichoptic stereoscopic presentations to consciousness of egocentric and relative stereopsis in natural seeing, emphasizing the art, rather than the science, of treatment.

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INTRODUCTION

The digital age promises a quantum leap in the nonsurgical treatment of strabismus.

New computerized vision therapy technologies, 3D movies, and the soon-to-explode field of virtual reality all promise advances in the presentation of stereoscopic dichoptic displays technically impossible for most of the history of strabismus therapy.

In a stereoscopic dichoptic display, we present each eye with a target that is unseen by the other eye. The two targets are slightly different just as the views from two eyes in the natural environment are slightly different. Sensory fusion allows the binocular illusion that dichoptic targets in physically different positions are unified, creating the perception of depth and often encouraging the alignment of deviated eyes.

Clinicians have long used such displays in the treatment of strabismus. By the beginning of the twentieth century, Javal[1] in France and Worth[2] in England were already using mirror stereoscopes and major amblyoscopes (modified mirror stereoscopes) to produce dichoptic displays. These instruments, however, created a number of challenges:

1. A limited field of view excluded the peripheral fusion that is largely responsible for maintaining alignment. As Brock,[3] a half a century later would write, "aversion to fusion seems to be limited mainly to the macular and paramacular region. For this reason fusion training should begin with the periphery and only gradually include the center." The dichoptic targets of stereoscopes and major amblyoscopes were just too central.
2. In approaching the sensory system, the motor system was often ignored, the eyes being allowed to remain in their strabismic posture while the illusion of sensory fusion occurred, combining targets that physically had nothing to do with one another.

3. For those adapted so that eye position allowed an accurate perception of the world free from the binocular illusions of diplopia and confusion, the true perception of the instrument's physically separated apertures was often more perceptually compelling than the illusions of blending and depth created by dichoptic targets. As Brock[4] wrote, "the squinter … is apt to resent the fact that *he no longer can see things as they really are and as he knows them to be.*" Similarly, Flax[5] commented that strabismics "have learned to utilize those aspects of the incoming eye signal that are consistent with their logic and with their language constructs."
4. Binocular illusions learned in an instrument that divorced the dichoptic images from interactions with hands and body often did not transfer to natural seeing. Aware of such challenges, Brock,[6] by the middle of the twentieth century, had developed the use of free-space anaglyphic stereoscopic displays. His stereo motivator[7], as it came to be called, projected stereoscopic images, which allowed the direct comparison of dichoptic display illusions to real objects in a room and allowed fusion confirmed by balance and movement. The lessons that Brock taught can now be advanced by digital technologies. Just as the increased safety of anesthesia and fellowship programs for the training of surgeons eclipsed nonsurgical strabismus treatment in the middle of the twentieth century, so will the advent of digital technologies restore the contributions of nonsurgical strabismus treatment in the twenty-first century.

Today's digital instrumentation and blending of monocular and binocular cues in 3D movies provide a welcome expansion of Brock's innovations. It is not the digital dichoptic tools by themselves, however, but the knowledge of their use as a springboard to natural seeing that will revolutionize nonsurgical treatment of strabismus. This paper—based on my[8] forty years of experience in treating strabismic patients, years including the transition into the digital age—provides one strategy for how that revolution could occur.

Depth Perception

While allowing increased acuity, a spare eye, and an expanded field of view, the principal advantage of binocularity is enhanced depth perception, particularly the appreciation of stereopsis. There is little doubt on the importance of stereopsis. Levi, Knill, and Bavelier[9] have summarized the literature on how "stereopsis matters" in the areas of driving, visually-guided hand movements, motor control, walking, visual feedback in control of movements, everyday activities and adaptations to changes in terrain.

If we divide space into three coordinates or dimensions, x-axis or width, y-axis or height, and z-axis or depth, then depth perception is the ability to determine the position of objects on the z- axis in free space … or to imagine a z-axis in photographic images or realistic art. Depth perception can include accurate objective behavior in quantifying of space. It can also include the subjective qualitative experience itself. In an attempt to distinguish the quantitative and qualitative aspects of depth perception, Vishwanath has provided the following attempt at clarification:

> *I define "visual perception of depth or 3-D structure" to generically refer to the perception of the third dimension, in pictures or real scenes, with one eye or two, regardless of the cues inducing it or the qualitative impression associated with it. This includes the perception of both depth order and quantitative depth (e.g., the perception of 3-D shapes and locations of objects in a 3-D pictorial space). "Stereoscopic vision" I take to literally mean "vision through a stereoscope" or, less literally, to refer to "binocular depth perception": the visual perception of depth*

on the basis of binocular disparities. I reserve the term "stereopsis" for the following: The characteristically vivid impression of tangible solid form, immersive negative space and realness … that obtains under certain viewing and stimulus conditions.[10]

Like Vishwanath we will use "depth perception" in his first sense to include all z-axis appreciation, including that in pictures. We will, however, more traditionally, use "stereopsis" to include both correct binocular localization of either natural or "dichoptic images," emphasizing the subjective qualitative "vivid impression of tangible solid form and immersive negative space and realness" or what Barry has called "a palpable volume of empty space"[11] If the truth of treatment emerges from the sum of the perspectives, then additional perspectives on the division of depth perception may provide insights for understanding our treatment approach.

Monocular Versus Binocular Cues

Depth perception is most commonly divided into depth from monocular cues versusdepth from binocular cues. After Adler,[12] monocular cues include interposition of one object in front of another, customary size of objects, color and haziness of objects, convergence of lines to the vanishing point, shadows, and monocular parallax. To this list, we will add "looming," which, like motion parallax, also requires comparison across time, not just across space.[13] Binocular cues, again according to Adler, include convergence, binocular accommodation, and stereopsis.

Artificial Versus Natural Depth Perception

Another way to divide binocular depth perception is between artificial and natural perception of depth. Photographs, realistic paintings, and 2D movies are all examples of artificial depth. The mind creates the illusion of depth where none exists, transferring flat images into three dimensional perceptions. When viewed through a monocular aperture, for instance, photographs with good perspective may become so three-dimensionally vivid that they approach the Greek *stereos,* meaning "solid," from which our term *stereopsis* is derived. To capture this vividness, Vishwanath[14] uses the term "monocular stereopsis" for the perception. In this paper, however, to avoid confusion we will reserve the term stereopsis for binocular perception.

While the Verhoeff Stereopter and Howard Dolman Test both test depth perception naturally, the Titmus Stereo Fly and Wirt tests are both examples of artificial stereopsis. The Fly and Wirt test are both physically flat. Any depth is, again, an illusion occurring only in the mind, not the apparatus, illusion being what often occurs when we transfer how we "do" vision in a familiar environment to how we "do" vision in a novel or artificial environment.

All dichoptic presentations, 3D movies included, are examples of stereoscopic illusions, not natural stereopsis. The perception of images springing off the movie screen is not to be found in the physical movie theater but in the minds of the viewers wearing the polarized glasses. As will be described below under "Natural Stereopsis," care must taken to ensure that dichoptic illusions, once appreciated by those with strabismus, are transferred to appreciation of stereopsis in natural seeing.

Central/Relative Versus Peripheral/ Egocentric Depth Perception

Burian[15] provides a third highly profitable way to divide localization of depth: relative versus egocentric. Suppose, for instance, a woman raises two fingers at arm's length before her face and compares the fingers' z-axis position in space. If attention is constricted to the two targets, this is an example of relative depth perception (RDP). Both the Verhoeff Stereopter and the Wirt test, for example, quantify RDP as the viewer tries to determine the relative position of targets. If however, in the two-finger example, the viewer instead considers the distance of the two fingers from her face and is aware of the space in between her nose and both targets, egocentric depth perception (EDP) is being appreciated. During this heightened awareness of EDP—in my experience as a viewer and clinician—RDP often improves. As Vishwanath[16] has hypothesized, "stereopsis is a qualitative visual experience related to the perception of egocentric spatial scale. Specifically, the primary phenomenal characteristic of stereopsis (the impression of "real" separation in depth) is proposed to be linked to the precision with which egocentrically scaled depth (absolute depth) is derived." Whether or not Vishwanath's hypothesis is true, the key to improving stereopsis in the therapy room and in real space is very much linked to attention to EDP.

In the therapy room, the closest clinicians come to quantifying EDP is, perhaps, SILO (Smaller In and Larger Out), the perception in which dichoptic targets appear smaller and closer with base out disparity causing convergence and larger and farther away with base in disparity causing divergence. While only stereoscopic or third degree dichoptic targets offer RDP, simultaneous perception targets (first degree fusion), flat fusion targets (second degree targets) and stereoscopic (third degree fusion) targets all may be perceived to float in space using EDP. When perception of spatial context is included, all targets may take advantage of EDP!

Measuring the accuracy of EDP is estimated by comparing the position of the two eyes and the actual location of each eye's respective target (Figure 1).

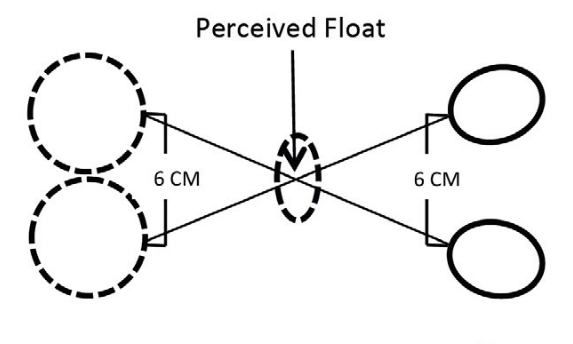

Figure 1

If a patient's interpupilary distance (PD) is six centimeters and the base out disparity of the target is six centimeters, the eyes will be converged to (and the fused image of the target should be localized) half way between the patient and the physical location of the disparated target. If the patient's PD is six centimeters and the target disparity is three centimeters the target should be perceived to float one fourth of the distance out between target and patient. If, for the same patient, the target disparity is twice the PD the patient should perceive the target to float outward three fourths of the way from the target's actual position and the patient's face.

For the purposes of therapy, I imagine that egocentric localization and SILO are closely related to the area of space the viewer selects for viewing. If, for instance in the above finger example, the viewer selects only the two fingers to view, there will be awareness of only central or relative stereopsis. If, however, the viewer selects all the space between his eyes and the two fingers then both central RDP and peripheral EDP will be perceived.

"Opening appreciation of space" to allow for peripheral EDP/egocentric awareness of depth can be accomplished in some cases by coaching to patient to be aware of the distance (volume of air or space, not an introverted estimate of feet or inches) between her nose and the target. Other viewers are more likely to open up appreciation of space if coached to "try to see everything in the room at once," or if coached to be "simultaneously aware of the right and left walls at the same time" or "be aware of the length of the floor and ceiling at the same time." The words "be peripheral" can be used, but only if the patient understands that "being peripheral" includes awareness of space, not just on the x-axis, but on all three axes: x, y, and z.

The following proposed treatment approach will provide examples of this principle.

TREATMENT

In our approach to using stereoscopic vision in the treatment of strabismus, two general rules apply: 1) work with the eyes aligned or approximately aligned and 2) encourage peripheral awareness.

Alignment

"Anomalous binocular correspondence (ABC) is diagnosed when the two eyes' foveal images are perceived in different visual directions."[17] Unless the habitual angle of deviation is disturbed, the patient typically perceives the objects related to foveal images in their correct position in space, as if the patient knew where the eyes were pointing.[18] The perception is in agreement with what the body, including the hands, would confirm to be true. If the right eye is looking straight ahead at a monitor, and the left eye is turned toward a copy of *War and Peace* on the bookshelf to the left of the monitor, the exotropic patient with ABC will use the right eye to perceive the monitor straight ahead, which could be confirmed by touch. The left eye will simultaneously see *War and Peace* in its veridical (true) location to the left, again confirmable by touch. When both monitor and book are fortuitously aligned with a visual axis, both monitor and book may simultaneously be perceived as clear, although not necessarily equal. (As one patient described his simultaneous perception, referring to the diminished perceptual state of his non-preferred, non-fixating eye, "My 'big eye' sees one thing, while my 'little eye' sees the other." Such qualitative, perceptual differences between the two eyes may help the strabismic patient keep track of the real locations of their perceived images.)

When ABC exists, the key to eliciting stereoscopic vision is to get the patient voluntarily pointing the two foveas in the same place at the same time so that sensory and motor information will co-vary[19] and come to coincide. Or put another way, with both eyes voluntarily pointed at the same target, oculomotor information will now be confirmed by both bifoveal superimposition and hand information. All three will now support perceptual fusion of the target.

Precise stereoscopic vision depends on precise ocular alignment and gross peripheral stereoscopic vision depends on at least approximate alignment. In the words of Brock in his lecture notes, "It is the nature of the posture which determines the nature of the responses … while the eyes are in strabismic posture, the individual thinks strabismically, but the minute his eyes are in a normal posture he ceases to think strabismically and thinks the way we do."[20] Thus whether or not a patient has ABC, stereoscopic vision is likely to be appreciated when the eyes are voluntarily aligned or at least approximately aligned to allow a peripheral fusion lock. Normal retinal correspondence (NRC) versus ABC need be considered when the eyes are deviated but not when the eyes are aligned and stereoscopic vision is present. Even when the eyes are only approximately aligned so that a slip of eight or less prism diopters are observed on a unilateral cover test, the clinician concentrates not on reducing the degree of the slip but on increasing the accuracy of localization, which in turn reduces the degree of the slip. Greater accuracy of localization simply requires the eyes to be more accurately aligned.

For many patients with intermittent exotropia, dichoptic stereoscopic targets or hand-eye targets such as placing a pointer in a drinking straw held parallel to the face, encourage alignment. Such stereoscopic demands may prompt alignment at four or five inches in front of the nose even though stereoscopic vision and binocular alignment are absent at traditional testing distances. Similarly with esotropia, the eyes will often align at some point in space closer to the face. To determine this distance, Brock[21] described a test in which a penlight is slowly moved towards a patient's nose. Brock found three responses: 1) the patient actively takes up and maintains binocular posture over some distance, exhibiting a "centration range." 2) The patient exhibits a "centration point" allowing the penlight to rest at the intersection of his two eyes but making no effort to maintain binocular posture when the penlight is moved on the z-axis. 3) The patient exhibits neither a centration point nor range but actively avoids bi-fixating the penlight. Rather as the penlight approaches, the patient continues to over converge until, at some point, the patient actively diverges, again to avoid bi-fixation.

When binocular alignment is more robust, stereopsis follows. Regarding the three groups Brock identified (above), peripheral stereoscopic vision was demonstrated within the centration range among 90 percent of the first group, 53 percent of the second, and 13 percent of the third—who, Brock suspected, align their eyes for the stereo target, but not for the penlight. Brock concluded, *"3D appreciation is solely a function of bi-fixation:* When the eyes are not centered on the object of regard, the latter cannot be perceived stereoscopically. When they are centered, 3D is rarely absent …"

With this in mind, whatever stereoscopic testing and cover testing reveals at normal testing distances during the exam is not important. Those exotropes who align their eyes at any distance for stereoscopic targets and those esotropes, with or without ABC, with gross stereoscopic vision somewhere within a centration range are typically ideal candidates for the for the therapy approach outlined below. In my experience it is not uncommon to find patients who could not perceive the stereo fly initially, but could perceive it after therapy.

Peripheral Awareness

As cited above, Brock suggested "aversion to fusion seems to be limited mainly to the macular and paramacular region. For this reason fusion training should begin with the periphery and only gradually include the center." Similarly, both Ludlam[22] and Flax[23] have reported the use of binocular defocus to promote fusion. While defocus may prove an initial aid in allowing bi-fixation, another key to gaining alignment and stereoscopic vision, especially in esotropes prone to ABC, is peripheral awareness. Patients select an area to examine. The larger the area simultaneously examined rather than examined by sequential processing and saccadic eye movements, the more "peripheral" the vision. It is convenient to think of the area simultaneously examined as a "sphere of attention." In actual fact, peripheral awareness includes simultaneously expanded awareness on all three axis: X, Y, and Z. For ease of presentation, Figure 2 illustrates a circle rather than a sphere of attention. The circle includes the screen, the floating target, the walls, and the distance between the patient and the screen. Simultaneously imagining a floor and ceiling would create a sphere. The sphere may be enlarged by expanding attention on the X, Y, and or Z axis.

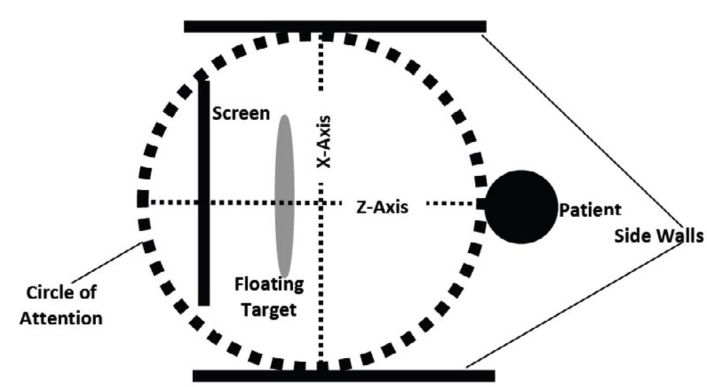

Figure 2—Circle of Attention

Some patients do better attending to a single axis; some, by attending to two or three. Peripheral awareness, or an expanded sphere of attention, may be encouraged in any number of ways:

- Begin with large targets without central detail. Coach the patient to be aware of the outside of the target.
- Hold the above-described large target as close to the patient as the centration range permits and, again, coach the patient to be aware of the outside of the target. The closer a given target is, the more peripheral it becomes. As the distance from the target increases the

target becomes more central and requires more accurate alignment.

- Shake the target. The fovea responds best to stationary, high contrast, targets. The peripheral retina responds to moving, low contrast targets. Shaking targets, therefore, discourage foveal attention to detail and encourage peripheral awareness and appreciation of peripheral stereoscopic targets (via peripheral retinal stimulation).
- Blur the target. Again, as reported by Flax and Ludlam, blur removes details that encourage central attention and makes it easier for the patient to maintain peripheral awareness. It is the patient's attention to detail, not the details themselves, however, which trigger ABC and a loss of stereopsis. Blur is a tool to help work around obsessive attention to detail. As the ability to maintain peripheral stereopsis develops, blur may be slowly reduced. Indeed, when many esotropes first tap into the peripheral system they report that central details are blurred. As peripheral stereopsis and a peripheral lock become more second nature, patients generally learn to temper their peripheral awareness allowing more and more central stereopsis and clarity simultaneously.

Three other ways are generally useful to get the patient into the egocentric awareness system: divided awareness, gestalt awareness, and egocentric awareness.

Divided Awareness

Coach the patient to be simultaneously aware of the walls to the right and left of the target or to be simultaneously aware of the floor and ceiling, thus "dividing" awareness. If the patient is unable to simultaneously select the two side walls to view, and instead looks first at one wall and then at the other, then the peripheral vision may be elicited by encouraging the patient to look towards the center of the screen rather than alternating attention. It may be easier for the patient to see simultaneously the outer boundary of the background upon which the target appears or is being projected: the outer boundary of the vectogram holder, video monitor, or silver screen allowing the use of polarized targets. Divided awareness sometimes fails because, rather than open the sphere of attention, the patient merely alternates attention or becomes simultaneously aware of two small areas at once without opening perception to include z-axis awareness.

Gestalt Awareness

A second way to create peripheral awareness is to train the patient to see the screen as a gestalt. One way to accomplish this gestalt awareness is to ask the patient to look at the unprinted back of a business card held several feet away. Most patients will perceive the business card as a business card instead of going central to see the card as a collection of individual edges and corners. If one of the patient's eyes are covered and the card is slowly moved toward his face, at some point you may see the patient's eye begin to move as he begins to examine the parts of the card rather than see the entire card at the same time. The second this occurs, make the patient aware of how it is different to see the whole card at once without moving his eyes. Move the card back out and have the patient, again, see the card as a card. When the patient can see the card as a card, have the patient see the silver screen as a silver screen, that is, see the entire screen simultaneously. When shifting into this mode of seeing, patients often report perceptual blurring of the 3D target and silver screen. Stereopsis is nevertheless elicited. As mentioned above, as more control of shifting from the central to peripheral mode is developed, it generally becomes possible to achieve a balance between the two, allowing clear seeing of more central targets in the presence of peripheral stereopsis.

Egocentric Awareness

A third method to get the patient peripherally aware is to coach him to be simultaneously aware of all the space between his or her nose and the screen or target. The key to such egocentric seeing is to perceive the space, not introvert to analytically estimate the distance of the space in feet or meters. Other ways to encourage this awareness of z-axis space is to place a dowel stick next to the target and have the patient, without moving his eyes to the side, be simultaneously aware of the entire length of dowel (a sort of "z-axis gestalt awareness) and the target's position compared to the dowel. If the target is close, a finger may be used. If the target is six feet away, a six-foot dowel may be used.

In the case of using the dowel stick, the following step by step sequence might be as follows:

- Dowel close to the target or looping the target, thus not requiring the patient to select too large of an area for viewing, but not encouraging central awareness of the target
- Dowel further to the side of the target, thus requiring the patient to open up peripheral vision a little further
- Dowel at the edge of the screen, thus encouraging the patient to simultaneously see the whole screen
- Encouraging patient to see the float of the target in relationship to the length of the floor and ceiling, or the length of the walls of the room.

For some, the use of the dowel fails because it occludes part of the projected vectogram (e.g., quoit), thus creating a disparity between monocular and binocular cues.

Responsibility and Control

The easiest way to make a patient take responsibility for an error is to teach the patient to make the error on purpose. If, for instance, a child, while tracing a maze, kept allowing his pencil tip to go outside the maze, the therapist would alternately coach the child to "Trace inside the maze!" and "Trace outside the maze!" Soon the child would take responsibility for tracing outside the maze and control the pencil tip to stay inside the maze. If a child similarly had trouble with pursuit movements, taking his eyes off the therapist's moving bead, the therapist would alternately coach the child to "Look away from the bead!" and "Look towards the bead!" until the child knew when he was looking at the bead.

In the case of the quoit with the dot on the wall, once the patient has stereopsis at one distance, the therapist can coach the patient to shift back and forth between central and peripheral attention to teach the patient how to shift voluntarily into the stereoscopic mode. The therapist can use the following instruction set stressing central versus egocentric, gestalt, or divided attention:

- Be aware of the distance between your nose and the dot (or be aware the silver screen as if it were a business card or be aware of the two walls simultaneously—whatever instruction elicits stereopsis). Get the quoit to float out as far from the dot as you can.
- Now look at the very edge of the dot (preferable with a very slight indentation created in it). Look at the tiny indentation in the dot. Make your vision small and concentrate on the indentation. Can you make the quoit go flat?
- Now be aware of the space between your nose and the dot (etc.). Can you get the quoit to float outward again?

Repeat this sequence until the patient can take responsibility for going central and flattening the quoit and taking control to go peripheral and get the quoit to float. As Birnbaum[24] has described, patients often attribute changes in perception to the apparatus rather than to themselves. Thus, to begin with, patients may perceive that the quoit is floating or flat as if they have nothing to do with the perception. When the central-peripheral alternation between responsibility and control procedure is complete, the patient should take responsibility for making the quoit go flat and know that he is in control of the quoit floating. Also, the patient's learning to create a lack of stereopsis on purpose generally allows him or her to create stereopsis on purpose. The patient needs to understand that the float of the quoit is in the patient, not the quoit.

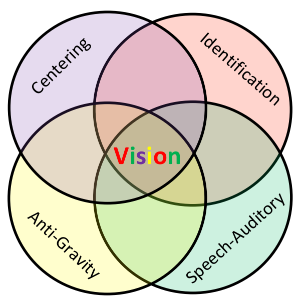

Figure 3—Skeffington's Four Circles

Language

Optometrists have noted language's role in vision at least since the time that optometric pioneer and educator A.M. Skeffington, as legend has it, captured the visual process by scribbling a four-circle Venn diagram on a napkin. The circles (see Figure 3) included "centering" (selecting an area of space for attention and meaning), "identification" (the process by which one knows what things are), "anti-gravity" (sense of body position/movement), and "speech/auditory" (language/analysis of sound). Metaphorically speaking, vision emerges to become greater than the sum of the four circles for the purpose of deriving meaning and directing action.

In abstract language, such as the phrase "counting all the stars in the universe" real action and vision are abandoned for analogy or metaphor. The metaphor may inspire action or mental images, but you can neither count nor accurately imagine all the stars in the universe. In concrete, perceptual language, such as the phrase "picking up the marble," language is merged with vision to direct action; in fact, such action, vision, and language are often learned in unison—and, therefore, genuinely trusted.

In the case of unexperienced actions (actions never directed by the visual process), language again reduces to abstraction, analogy, or metaphor. The words are not understood in the fullest perceptual sense any more than a non-surgeon understands surgery in the fullest perceptual sense. If, for instance, a seer depends on sequential processing rather than simultaneously selecting larger areas of space to view, then he may have no perceptual understanding of the difference between the phrases "seeing a room with things in it" and "seeing individual things in a room." He may be able to repeat or comment on the words, but the perceptual distinction between the two phrases may elude him.

Brock was aware of the restriction of language for those unaccustomed to experiencing stereopsis:

> *When stereoscopic fusion prevails, the patient is conversant in our language and when stereoscopic perception is absent he speaks a foreign tongue which most of us simply do not understand. For this selfsame reason we misinterpret his statements by applying them to our own mode of seeing instead of to his.*[25]

Consider an example or this breakdown of language. Suppose the patient is viewing the quoit and dot target on the wall and the therapist asks, "Which is closer, the dot or the quoit?" The patient replies, "The quoit." Asked, "If you were to walk down to the wall, which would you come to first, the quoit or the dot?" the patient again replies, "The quoit." Similarly, when asked, "Where is the dot?" the patient will correctly answer, "On the wall." But when asked, "Where is the quoit?" the patient may answer, "On the wall." This last response at first seems to contradict the previous three, but actually the patient is correct. In the illusion, the quoit may be perceived closer than the dot, but in actual fact, both the quoit and dot are physically on the wall. If the patient were to walk down and touch them, his or her hand would confirm the correctness of the response.

One way to explain this behavior is that to the strabismic patient, the question "Where?" means, "Where would my hands and body (not my eyes) tell me the target is?" This would be only natural if the patient, to correctly understand the world, had come to ignore perceptions that conflict with his hands. Since dichoptic illusions conflict with hand-body input, the patient ignores the stereopsis illusion, just as he ignores such illusions as luster, rivalry, or superimposition, any one of which could result in constant confusion and diplopia. Instead the patient perceives what past actions have proved to be true. Visual illusions lie; the hands do not. The response is not unlike asking a person to look at a photograph of a dog standing in front of a fire engine. To the question, "Which is closer, the dog or the engine?" the viewer would answer, "The dog." But when asked to "touch the dog" and "touch the engine," the viewer would correctly touch both on the same plane. The adapted strabismic is likely no more tricked by the quoit binocular-cues illusion than the photograph viewer is deceived by the photograph monocular-cues illusion.

To work around the language problem, Brock suggested the following approach:

> *I, therefore try to explain to my squint patients how their mode of sight differs from ours and what strange visual falsifications they have to expect before they may gain normal binocular vision.*[26]

In the case of the quoit and dot the therapist might explain, "You're right. Both the quoit and dot are actually on the wall, but the overhead projector and the glasses can make things *seem* different than they really are. When I'm asking you where the quoit is, I'm not asking where the quoit really is but where it *seems* to be. The quoit's position is an illusion. It is not real. We are developing your ability to note what your eyes feel like as you see that illusion even though it conflicts with what your hands would normally tell you is true." Even if the patient has not voiced his concerns, he often feels confused with the whole endeavor. The therapist's communicating about the difference between eye information and hand information may be useful. At the very least, such communication signals to the patient that the therapist understands the patient's dilemma between the illusions of binocular input and habitual body action in habitual space. With such language-confused patients the therapist should continue with the *"seem* to be" rather than the *"is"* instruction sets.

Having considered some general suggestions for dealing with expanding the size of the sphere of attention, taking responsibility and control, and dealing with language, we consider the use of some actual dichoptic targets in developing stereopsis in strabismus.

Vectographic Stereoscopic Vision

Traditionally, at least since the time of Brock, red-green anaglyphs have been used to create dichoptic stereoscopic vision in the treatment of strabismus. Since most patients, in the author's experience, have an easier time perceiving vectograms than anaglyphs, this paper will stress vectographic and, with the exception of red-blue computer-generated randot stereograms, largely ignore anaglyphic procedures, not that the training tools suggested below could not be done anaglyphically.

Quoit with Dot at Near

A great tool for eliciting stereoscopic vision in esotropia is a quoit vectogram with a nickel-sized dot on the clear plastic handheld vectogram holder. While the quoits are dichoptic, one being seen by each eye, the dot is real. Both eyes are seeing the same dot as a point of reference.

When beginning, especially with a younger patient who is unfamiliar with the apparatus,

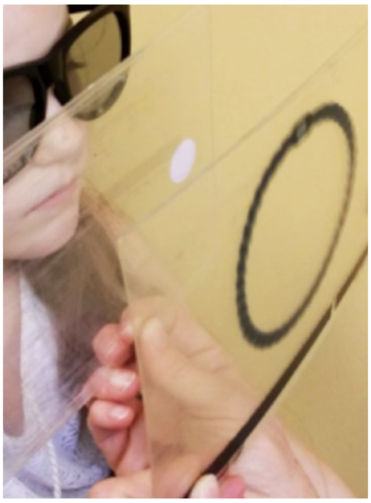

Figure 4: Demonstration of Quoit Behind Dot

the therapist holds the clear-plastic holder with dot in one hand within the centration range (see Figure 4) and, with the other hand, places both superimposed right and left quoit slides physically first in front of the holder and then behind it, asking the patient if the quoit is in front or behind the dot. When the patient has demonstrated an understanding of "in front of" and "behind," the therapist inserts the two quoit slides into the holder, centering them around the dot, and disparates the right and left slides repeatedly between C and 3. Note here that the therapist is not trying to build ranges, which would cause the eye to deviate and could invite an ABC response. Rather the therapist instructs the patient to watch the dot with aligned eyes, disparates the quoits, and asks the patient about the perceived relative positions of the dot and rope.

The area of space selected for viewing may be increased by using a number of approaches suggested in the above peripheral vision section:

- Shake the two quoits compared to the dot even while moving the quoits relative to each other between 3 and C (peripheral retinal stimulation).
- Ask the patient to look towards the dot but to be aware of the shaking quoit out of the corner of his eye (peripheral retinal stimulation).
- Ask the patient to be aware of the whole room while judging if the quoit is in front of or behind the dot (divided attention).
- Ask the patient to see the entire plastic holder simultaneously as if it were a business card (gestalt attention).
- Ask the patient to be aware of how much space there is between the dot and his nose (egocentric attention).

While any of these approaches may be useful in eliciting EDP (egocentric depth perception), the patient's responses often give clues whether he is in the relative/central or egocentric/peripheral mode. For instance, when the quoit is at 3 (base out disparity), the patient may report that the quoit is in front, but at C (base in disparity) report, "Now the dot is in front." This response suggests that the patient is attending to RDP (relative depth perception) rather than EDP. The perceived z-axis position of the dot should not be moving because the true position of the dot is not changing. The perceptual position of the moving quoit should be changing. If the patient is in the egocentric mode, he should perceive the quoit moving in front of and behind the dot compared to himself. Asking the patient to attend to the space between his nose and the dot, generally shifts him into the egocentric mode, stabilizes the absolute position of the dot, and allows the patient to perceive the quoit moving in front of and behind the dot.

Once peripheral awareness has been trained to maintain grossly aligned eyes through some range of z-axis movement, the goal is to make the target more central. The closer the holder is to the patient's face, the more peripheral the quoit is and generally the more accurate the localization. As the vectogram holder is moved out farther away from the patient's nose, the quoit and dot become a more central target. Also if the eyes are not diverging as the target recedes, the angle of strabismus is increasing relative to the dot. Such factors cause the perception of the position of the quoit to become confused. Thus, the patient is definite about the quoit's position when it is near. As the dot is moved farther away and into the "zone of confusion," the patient is no longer certain of the quoit's position. Rather than being able to circle the quoit with a finger or pointer accurately, the patient gives vague reports such as, "the quoit seems to be somewhere in front of the dot." Also, for a given base-out disparity, the farther the dot is moved away from the patient, the greater the amount of float the quoit should appear to have relative to the dot. The therapist knows the zone of confusion has been reached when, as the dot is gradually moved farther from the patient, the patient begins to perceive the relative distance between the quoit and the dot to be stabilizing or even decreasing, as if the quoit is now retreating back *closer* to the dot.

Quoit with Dot on Wall

Using an overhead projector, the therapist projects the quoits with the dot target onto a silver screen that does not depolarize the light. This target is half natural (the dot is seen simultaneously by both eyes, as are the contents of the room) and half dichoptic (each eye is exposed to a different ring). The therapist positions the patient so that both eyes may be grossly aligned on the projected dot. If this requires the patient to move too close to the screen, then the shadow of the patient's head can serve as the dot.

As the patient views the dot, the therapist disparates the quoits between C and 3, base in and base out (again the therapist is not building ranges, but introducing disparities so that each eye's slightly different perspective elicits stereopsis). The patient is coached to increase the size of his or her sphere of awareness and to report if the quoit appears to be in front of or behind the dot. After correct stereoscopic vision is achieved with the patient standing closer to the dot on the wall, and the patient has a certainty of where the quoit is floating, the therapist can coach the patient as far away from the wall as he can maintain certainty of the quoit's location. Past that distance, the patient may be able to report that the quoit is off the wall but, having entered the zone of confusion, will no longer be certain of the quoit's position. As outlined above, a number of instruction sets and variations of physical parameters can be used to manipulate peripheral awareness and elicit the patient's perception of stereopsis and correct stereo-localization:

- Start closer to the wall. Coach the patient to "look toward the dot, but keep your attention focused on the entire ring at the same time."
- Gradually move farther away until certain localization is lost.
- At a distance where the patient has some perception of the ring's float, work "responsibility and control," alternately having the patient go central to lose the float and then go peripheral to regain the float.
- Cover one of the patient's eyes and lose the EDP. Uncover the patient's eye and regain fusion and EDP.
- Have the patient look at his finger held a few inches in front of his face. Then have the patient return his attention to the screen, become peripheral, and again see the float.
- Coach the patient as follows:
  - "Be aware of the right and left walls at the same time." (divided attention)
  - "Be aware of the floor and ceiling at the same time." (divided attention)
  - "Be aware of the distance between your nose and the dot." (egocentric attention)
  - "Be aware of how long the floor is between yourself and the dot." (egocentric attention)
  - "See the entire silver screen simultaneously as if it were a big silver business card." (gestalt attention)
  - "Constrict your attention to the very edge of the dot and make the quoit go flat on the wall. Now, see the side walls (entire screen, the space between you and the dot—whichever works) and

make the quoit float." (Responsibility and control)

- Arrange the room physically to increase appreciation of stereopsis in the following ways:
  - Adjust the overhead projector to blur the quoit. Gradually reduce the blur as stereopsis and correct localization can be maintained.
  - Shake the quoit to encourage peripheral awareness (peripheral retinal stimulation).
  - Place a chair between the patient and the dot and have the patient be peripherally aware (as described above). Compare the location of the quoit to the chair back in order to increase z-axis awareness. At first, the patient's constricted sphere of awareness may require the chair to be aligned directly with the quoit. As the size of the sphere of awareness increases, allowing simultaneous awareness of the chair and ring, the therapist can move the chair further to the side to increase x-axis awareness.
  - Align more than one chair along the patient's z-axis to extend z-axis awareness, stereopsis, and correct localization.
  - Arrange two chairs between the patient and the screen, but place one to the right side and one to the left side of the screen. Coach the patient to be simultaneously aware of the two chairs, the dot, and the floating quoit.
  - Have the patient hold a long dowel stick between himself and the dot on the wall. Have the patient try to see the entire length of the dowel simultaneously. With the aid of the dowel stick, while the therapist continues to shake the ring, the float can become quite dramatic. Alternatively, for some patients, awareness of the side wall can be more useful: Recall that the dowel may interfere with the perception of stereopsis due to the conflict between monocular and binocular depth perception cues when the dowel overlaps a portion of the quoit.
  - Have the patient use a shorter, lighter, dowel stick to tap the longer dowel stick at a point even with the perceived ring. Thus if the patient perceives the quoit as being close to the wall, he will tap the one stick against the other at that distance, etc.

Projected Spirangle
Stage I—Peripheral Stereoscopic Vision

Once the patient can alternately voluntarily choose to appreciate or not appreciate stereopsis with correct localization several feet away from the wall, we are ready to try the spirangle vectogram. To begin with, the therapist adjusts the overhead projector to blur the projected spirangle until its form is vague and its letters and other details are beyond recognition. Encouraging peripheral awareness, the therapist shakes the vectogram and encourages the patient to discern if the outside or the inside of the spirangle is closest. When the patient is able to see the float, the therapist adds the responsibility and control of central-peripheral alternation until the patient can control the appreciation of stereopsis and localization with the blurred target. Then the therapist reduces the blur until the patient perceives the target to begin to flatten. The therapist blurs the target just enough to restore the EDP and coaches the patient to use peripheral awareness—especially gestalt attention of the complete silver screen—to keep the spirangle floating, even as blur is slowly reduced. Indeed, the goal of the spirangle is to teach the patient to use peripheral awareness to maintain the target's float despite the introduction of central detail. Apart from the central-peripheral attention procedures encouraging responsibility and control, digital instrumentation is often more helpful in the development of peripheral attention in the presence of central stereopsis.

Stage II—Central Stereoscopic Vision

Once the patient has good appreciation of spirangle stereopsis with the vectogram perfectly clear, the therapist can direct the patient's attention to the alphabet within the conical structure of the target, with lines which spiral outward from center to periphery. Each of these larger letters is in a circle and surrounded by a square, as shown in Figure 5 (not to be confused with the tiny letters with suppression controls at the spirangle's center and end).

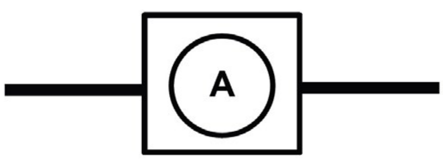

Figure 5: Spirangle Central Stereo

Depending on whether the circle has base out, base in, or no disparity relative to its square, the circle should be perceived as closer, farther, or in the same plane as the square (respectively). With letter A, for instance, the circle containing the letter should be perceived in the same plane as the square; with letter B the circle should be perceived closer than the square; with letter C the circle should be perceived behind the square.

As the patient searches for the alphabet and perceives if the circle is flat, in front of, or behind the square, the therapist needs to coach to patient to continue to see the entire spirangle floating out in space. Thus the procedure combines EDP and RDP, as well as spatial language.

Not all patients who can perceive some degree of float on the quoit will be able to perceive the float on the spirangle. Not all patients who perceive the float on the spirangle will be able to perceive the relative position of the circles and squares. Thus it is possible for patients to develop decent EDP while still lacking central RDP.

Digital Stereoscopic Vision

For digital therapy, we use the Computer Orthoptics® Liquid Crystal Automated Vision Therapy System (VTS4).[27] While the images of the VTS4 are dichoptic, the VTS4 procedures can be performed to stress real images in the real world as well. When, for instance, to increase peripheral awareness and egocentric stereopsis, attention is directed to awareness of the instrument framing the screen and images, both eyes are seeing the same frame.

While the projected quoit vectogram has certain advantages over the VTS4—being easier to blur without lenses and being better suited for working responsibility-and-control for alternate central-peripheral awareness—the VTS4 has a number of advantages over projected quoits:

- The liquid crystal glasses are flashing rapidly between the right and left eyes' images, making it difficult not to perceive the stereopsis—a feature which makes it more difficult to voluntarily flatten the stereopsis with central awareness. (The rapidly changing stimulus is similar in impact to shaking the quoits.) This persistence of stereo nevertheless provides a boon for many of those who cannot otherwise perceive stereoscopic vision.
- Unlike the projected quoits, the VTS4 allows the patient to get very close to the screen without occluding the target, thus the VTS4—like the quoit with dot at near—allows a more peripheral target at a distance where the esotropic patient's eyes are closer to being aligned.
- The VTS4 provides a wide variety of targets, some more peripheral, some more central, all of which can be varied in size to make them even more central.
- The VTS4 also allows an excellent bridge for coming to appreciate 3D TV, it being possible to connect a Blu-ray 3D Player to the same computer system.

The best targets for initially eliciting stereoscopic vision are the ring, the dog and ring, and the robot and ring. The same techniques that were used for the projected quoits may be used for eliciting peripheral/egocentric localization for these VTS4 targets:

- Being aware of the entire room to the sides of the instrument (divided attention)
- Being aware of the distance between nose and target (egocentric attention)
- Being aware of the rectangular gestalt of the screen frame as if it were a business card (gestalt attention)
- Pressing the Function 11 key to cause the ring to rapidly oscillate (peripheral retinal stimulation).

In addition, a number of other techniques may be used to facilitate appreciation of stereoscopic vision:

- Making the ring larger or smaller to optimize appreciation of stereoscopic vision at a given distance. A ring that is larger than the patient's ability to open up side vision is ineffective. A ring that is too small triggers strabismic posture and adaptations.
- Placing both hands on the screen, one on each side of the ring, being aware of both hands at the same time, and being aware of the length of both arms.
- Placing the tip of a dowel (or neoprene foam sword, to protect the screen surface) near the ring or other target to facilitate appreciation of stereoscopic vision without the need to fully expand the sphere of attention and open up peripheral vision. Once the stereopsis may be appreciated with the sword close to the target, the therapist positions the dowel increasingly farther to the side until the patient can open up side vision enough to use the rectangular screen frame gestalt to elicit egocentric localization. The goal is for the patient to be able to perceive not only the relative depth within the target, but the absolute depth of the target floating out into the room.
- As stereoscopic fusion improves, add covering and uncovering one eye or looking back and forth between a near finger and the screen.

The patient works these peripheral ring targets until maximum float is obtained using either rectangular screen frame gestalt attention or egocentric attention. Next the airplane-alphabet target and then the dolphin-fish target may be used to better combine RDP and EDP. The therapist fully increases the size of the airplane-alphabet target and has the patient remain aware of the screen frame gestalt until the patient can see the target's blue background closer and further than the screen frame as the target is varied between base-out and base-in disparity. It is often the egocentric localization of the blue background that allows the patient to overcome the central details encouraging a return to strabismic posture and loss of RDP.

As with the circle targets, the dowel stick or neoprene toy sword may be placed closer to individual letters of the airplane-alphabet target to encourage perception of egocentric localization. The patient should be encouraged to perceive simultaneously the entire length of the sword or dowel, that is, should be encouraged to see the gestalt of the sword rather than running eyes up and down its length to build a sequential perception of the sword; sequential perception frequently defeats both EDP and RDP.

The fish target may be used the same as the alphabet target, again seeing the position of the pale green background compared to the gestalt of the frame edge. Whereas the alphabet target matches monocular and binocular cues, with letter size corresponding to letter distance (so the patient's responses of depth can be based entirely on monocular cues), the fish target does not necessarily match size and distance. Thus it requires stereoscopic appreciation and gives a more reliable guide of the patient's binocular illusion status. (The stationary 'Figure-8 Racetrack' vectogram also varies size and depth independently.)

As digital stereo targets can be seen at greater distances from the monitor, their appreciation can be combined with such traditional movement activities as leg swings while balancing on one foot, walking rails, balance boards, or infinity walk[28]—all without loss of correct localization.

Computer-generated Randot Stereograms

With strabismics who are truly intermittent, their eyes being precisely aligned rather than grossly aligned when straightened, computer-generated randot stereograms can be used. As designed, the randot stereograms stress RDP, a smaller square being perceived to float outward from a larger rectangle. When these randot targets are used, however, care must be taken not to forget EDP. If the patient "gestalts" the rectangular edge of the computer screen, as practiced during previous digital procedures, the patient should perceive SILO of the larger rectangular background moving behind the screen and in front of the screen even as the smaller square floats relative to the rectangle. The larger rectangular target should float into the screen and get larger during base-in vergence and float outward and get smaller during base-out vergence. In this way randot stereograms can also be used to integrate RDP and EDP, which can later be transferred to natural conditions, as we will see in the "Natural Stereopsis" section below.

3D TV

The VTS4 has any number of targets working evermore central stereopsis. These targets can and should be used to develop stereopsis further, but once RDP and EDP can be maintained on the airplane and dolphin targets without triggering strabismic posture and spatial confusion, 3D movies can be used for further practice in both RDP and EDP, both in office and at home.

My therapists and I typically begin with the second track of Madagascar III. We stop the movie with the animated television set in the scene flying out at the patient. We prompt the patient to be aware of the outside of the screen and appreciate the egocentric position of the animated television set in space. We next stop the action of the film with the monkey in the wig applying makeup. Again, we encourage awareness of the edge of the screen and perceiving the egocentric position of the monkey's lips. Finally, we stop the movie when the pillow explodes into a cloud of floating feathers, and we train the patient on being aware of how attention to the outside of the screen gets the feathers to float out further.

Once the patient has seen the animated flying television, the monkey applying lipstick, and the floating feathers in 3D, we replay track 2 without stopping it, encouraging awareness of the outside of the screen and perception of the RDP and EDP in the scenes without stopping the action. We then jump ahead to track 12, again stopping the action throughout the circus scene, getting the patient aware of all the 3D moments before replaying the scene. While doing this, we encourage the use of all the tools learned in the therapy room during vectographic and digital presentations:

- The dowel stick or neoprene sword can be inserted in the scenes to encourage 3D perception while still allowing a constricted sphere of attention. Ideally, by the time 3D television is used, the patient has already learned to expand the sphere of attention to include the gestalt of the screen edge and expected EDP for the movie scenes.
- The patient can stand at greater distances from the screen.
- The patient can cover an eye and uncover it to compare the stereopsis while also learning to regain fusion after dissociation.

The same principles can be applied to any other 3D movie that makes use of both crossed and uncrossed disparities. When working 3D television movie perception the therapist needs to be aware of the times when maximum base out disparity is encountered to be sure it is properly perceived by the patient. Wikipedia provides a "List of 3D Films."[29] The list tells if the movie was filmed in 3D or filmed in 2D and converted to 3D. Converted movies typically contain little base out disparity with which to check localization. Most animated films are filmed in 3D and have both BI and BO, or crossed and uncrossed, disparity.

Once the patient demonstrates accurate 3D movie perception in the office, the therapist can assign 3D TV movie viewing at home and 3D movie viewing in the theater. An adult patient can be trained to ask herself periodically, "Am I aware of the border of the screen." "Am I aware of the distance between my nose and the screen?" "How far off the screen are the images popping?" If the patient is a child, a parent can be trained to ask the same questions.

Natural Stereopsis

The reason we work dichoptic stereo perception is not to familiarize the patient with binocular illusions, which may have no benefit beyond entertainment in the office or movie theater. We use stereoscopic vision procedures to train improved localization, which the patient may use to encourage alignment and improve performance. Unless, however, this awareness is carried beyond the confines of the therapy room, the treatment may be for naught. It is, therefore, useful to transfer what the illusions teach in the therapy room to real stereopsis in the real world.

Despite the advantages of stereopsis, even this goal is not beyond criticism. The surgeons Von Noorden and Campos,[30] for instance, have written, "Stereopsis is an epiphenomenon of normal binocular vision." An epiphenomenon is a byproduct of an action that adds no benefit to the action. The buzz of a bee is an epiphenomenon, for instance, because it adds no propulsion to the bee's flight. The term is popular in a philosophy that proposes that visual consciousness adds nothing to visual action. The argument is that since actions—like a tennis pro's swing—come before any conscious analysis of the action, consciousness lags behind the action,[31] consciousness (that is, conscious free will) is too slow to affect action. It may be true that consciousness played no part in the reflex action. However, whether conscious exploration may have played an active part in *learning* the swing is not considered. In the same way, even though consciousness of stereopsis may follow rather than lead visual action it does not necessarily exclude conscious exploration of stereopsis as a tool for teaching comfortable alignment. Despite a century of disagreements between those promoting the surgical versus nonsurgical tools for the treatment of strabismus,[32] my experience with vision therapy certainly supports this second view.

Mechanical versus Localization Alignment

Physiologically speaking, there is more than one way to align an eye. Maddox, in 1893, classified vergences as tonic, accommodative, disparity, or psychic (such as voluntary and proximal convergence).[33] Lenses altering accommodation can be used to alter vergences. In the treatment of strabismus, I find it convenient to divide non-accommodative vergences into two practical classifications: mechanical vergence and localization vergence. What I am calling mechanical alignment is the use of vergences to avoid diplopia (disparity) and encourage voluntary alignment (psychic). I can, for instance, voluntarily cross my eyes and control the separation of diplopic images in space. This method, however, requires that I learn to divorce accommodation from vergence if I am to see clearly with crossed eyes (absolute presbyopia helps).

Most exotropes and many esotropes similarly can voluntarily align their eyes, using voluntary convergence or divergence. The problem is that while using such mechanical vergences strabismics are often not comfortable without considerable training, including the use of base-in and base-out prisms to train convergence and divergence, as well as monocular and binocular accommodative rock to ensure full flexibility between accommodation and vergences. Patients using mechanical vergence expend concentration and effort that often results in stress. Unless the desire for cosmetically aligned eyes outweighs the inconvenience of the stress, mechanical vergence alignment is often abandoned.

I propose a second approach to align eyes: localization. Localization vergence similarly relies on both disparity and psychic vergence, but in a different way. Here, disparity is used in the creation of stereopsis rather than the avoidance of diplopia. Here, the eyes are aligned where the patient knows the target to be compared to self. Thus EDP plays a major role. While mastering the exercises designed to increase accommodative and vergence flexibility and comfort remains as useful as ever in achieving alignment, if the patient learns to utilize localization from EDP, then alignment is far less stressful. With this goal in mind, we turn to the art of transferring dichoptic stereoscopic vision to natural stereopsis.

Binocular Stick and Straw

When performing the binocular stick and straw procedure, the patient inserts a pickup stick in a drinking straw held parallel to his/her face. The procedure encourages alignment and perception of stereopsis for its completion. If mechanical vergence is the primary strategy being used, the patient voluntarily aligns his eye on the straw while inserting the stick into the straw. If instead, the patient is to use localization vergence, he is coached to expand the sphere of attention to include the previously learned z-axis awareness to judge the distance between self and straw. The awareness helps trigger alignment, reducing the effort typically needed to produce mechanical vergence. Thus each time the patient is about to insert the stick in the straw, the therapist reminds the patient to "see the distance between your nose and the straw" or asks, "Can you see how much air there is between your nose and the straw?" In this way the therapist is encouraging z-axis-egocentric awareness in the appreciation of stereopsis to help trigger alignment. The goal is to turn localization vergence into the primary strategy and mechanical vergence into a secondary strategy for fine-tuning ocular alignment if necessary.

Brock String

Physiological diplopia can be an artifact of extending the z-axis sphere of attention, causing the object fixated to be seen single and objects aligned closer and further to be seen double. If a Brock string—a several-feet-or-more-long string with three beads on it—is extended outward from the patient's face, and the patient extends z-axis awareness to see the entire length of the string simultaneously, physiological diplopia may create the illusion of two strings crossing each other to form an X, the intersection of which occurs at the point of bi-fixation, the distance at which the patient's eyes are converged. (As discussed previously, the sphere of attention, also allowing the physiological diplopia illusion, can often be expanded, depending on the patient's idiosyncrasies, using simultaneous gestalt awareness of the string length, egocentric awareness of the distance between nose and string end, or divided awareness of the walls to either side of the string.)

If for instance the string beads are placed at four inches, ten inches, and forty-eight inches from the patient's nose, and the patient's eyes are bi-fixating the middle bead to create the normal illusion, the patient will perceive the bi-fixated bead as single and the beads closer and farther double. If alternation is artificially suspended by command, and the esotropic patient with ABC is bi-fixating the ten-inch bead, he can typically be encouraged to behold the physiological diplopia illusion inside the bi-fixation point, but he perceives no such illusion at greater distances (typically perceiving a single string perpendicular to his face beyond the bi-fixated bead). Such a patient will perceive two strings converging into the ten-inch bead and a single string in its true position beyond the point of bi-fixation. Similarly, the patient will see the four-inch bead inside the bifixation point as double and the forty-eight inch bead beyond the bi-fixation point as single. Thus the patient sees a Y rather than an X.

The goal of the Brock string, however, is not to illicit the physiological-diplopia illusion. Apart from the string being an excellent tool for the development of z-axis gestalt awareness, the goal of the string is to use the illusion to provide feedback for bi-fixation while expanding the sphere of attention along the z-axis. Note that the perception of the strings intersecting as a 'Y' is as useful for this feedback as the perception of the intersection as an 'X'! Thus there is no reason for teaching the esotrope with ABC to see double beyond the point of bi-fixation — which could translate into seeing double in the real world — when it is not necessarily useful to do so. Instead esotropes can be trained to bi-fixate a bead once they have already been trained to diverge as far as the strabismus allows (with free space jump vergences and peripheral awareness). The instructions for working with the Brock string while perceiving a 'Y' intersection are:

- Throw the eyes maximally outward to make the three strings meet as far behind the bead as possible.
- Then converge just until the bead appears single, with the three strings intersecting at it.

Developing physiological diplopia inside the centration point typically offers little problem, so long as the patient is not alternating to maintain strabismic posture. The esotrope's visual world is beyond, not inside of the bi-fixation point, so the diplopia does not transfer to everyday seeing. Furthermore, while esotropes often avoid bi-fixation when their eyes are diverging, approaching from the near side of the target, bi-fixation is frequently better tolerated when the eyes are converging, approaching from farther to closer, possible because the esotrope has no previous experience inside of the centration point leading to adaptation and avoidance of bi-fixation.

Since the bead will appear single, even if the esotrope over-converges, care must be taken that convergence halts, the three strings intersect, and bi-fixation occurs exactly at the bead. Once such bi-fixation has been mastered, appreciation of egocentric and relative depth perception may be added by performing a modification of the Brock string procedure.

3D Stick and String

The Brock string is modified into a 3D procedure by having the patient, while maintaining bi-fixation, be aware of the length of the strings running into the bead, or be aware of the amount of space between the patient's nose and the bead. The bead is now substituted for the straw in the above-described stick-and-straw procedure. The patient holds a pickup stick parallel to his face and several inches to the side of the bead. While the patient maintains egocentric localization and perceives the three strings intersecting at the bead, he uses the stick to touch the side of the bead just as in the stick-and-straw procedure, where he placed the stick inside the straw. To accomplish this, both EDP and RDP are coordinated, the egocentric stereo forming a base for the relative-stereoscopic stick-andbead placement.

Once the patient is learning to coordinate eye position, stereoscopic perception, and hand movement by simultaneously bi-fixating the bead, perceiving the illusion of three strings meeting at the bead, and accurately directing the stick from the side of the bead to contact the bead, the therapist begins varying the distance of the bead from the patient's nose, placing the bead at various distances within the patient's centration range. Thus if the patient's range of bi-fixation were between two and ten inches, the therapist would place the bead at two inches then ten inches, then six inches, etc. At the ten-inch distance, the patient would get the three strings to intersect at the bead before making the placement. At closer distances, the therapist would have the patient diverge behind the bead and slowly converge until the two images of the bead just came together. This completed, the patient would again open up egocentric attention and make the stick placement.

The above procedure can be repeated with the string slanted to the right, left, up, and down compared to the previous straight-ahead position. We want the patient to be adept at bi-fixation, EDP, RDP and eye-hand coordination in all fields of gaze where binocularity may exist.

Vertical Stick and Straw

Vertical stick and straw procedure is just an extension of binocular stick and string. In this activity, however, instead of using a bead on the string, the patient uses a vertically-held drinking straw aligned parallel to the face. As with the bead, when the patient's eyes are aligned beyond the straw, the patient should perceive the illusion of the straw being double. If the patient has already mastered control of vergences using the string, the therapist now coaches the patient slowly to converge until the two straws just came together, again being careful not to allow convergence nearer than the bi-fixation of the straw. The patient, holding the stick vertically above the bi-fixated straw, lowers the stick into the straw. As with the string, the placements would be repeated at all distances that the patient can look beyond the straw, double the straw, and converge to fuse the straw before making the vertical stick placement.

Hand Mirror Stereopsis

Mirrors provide another means for manipulating the sphere of attention to transfer appreciation of stereopsis outside the therapy room.

If you hold a hand mirror before your face, you may count a few of your eyelashes in the reflection. If instead of concentrating on such central vision, you open your side vision and become simultaneously aware of the gestalt of the mirror frame encircling the glass, you should become aware of the actual location of your reflected face floating as far behind the glass as you are in front. At this point, instead of being locked in RDP and noting that the reflection of the tip of your nose is closer than the reflection of your cheeks, you have extended your sphere of attention to become aware of EDP and the position of your reflection compared to actual space.

When working with strabismus, the therapist may use this stereoscopic phenomenon in the same way that the quoit and dot were used. By encouraging the patient to "see the room to both sides of the mirror" or "see the entire mirror frame at once" or "see the space between you and the mirror frame" the therapist can coach divided, gestalt, or egocentric awareness, whichever best expands the sphere of attention and result in EDP. To work responsibility and control, the therapist can encourage the patient to alternate between center and periphery, constricting awareness to a single eyelash and then expanding awareness to the rim of the mirror frame and the egocentric position of the reflection in space, some distance beyond the mirror frame.

While working the hand-held mirror procedure, the therapist can check for accurate location of the reflected image by moving a hand toward the patient from well behind the mirror. The patient is coached to simultaneously (without shifting his eyes back and forth) be aware of his reflection and your hand and note when the hand and reflected image are at the same distance from his face. The absolute position of the reflected image should change as the distance of the mirror from the patient's face changes. To check the localization of the mirror image, the therapist simply has to observe if the reflected image is as far behind the mirror as the patient's face is in front of the mirror. If not, the therapist should coach the patient to expand his sphere of attention, using whichever method works best. Inaccurate localization signals that the sphere of attention is contracted or that the patient's eyes are not aligned. In the case of an esotrope, the therapist can move the mirror closer to the patient's face to secure more accurate alignment.

Because the mirror can be held mere inches in front of the face, the procedure is useful for esotropia as well as exotropia. The expansion of the sphere of attention can also be manipulated by changing the mirror size, larger mirrors requiring a greater expansion. Similarly, the closer a given size mirror is to the face, the more peripheral the patient must become to be simultaneously aware of the entire frame encircling the glass.

Wall Mirror Stereopsis

The following mirror stereopsis procedure is useful for intermittent exotropes when their eyes are aligned. It is also useful for intermittent esotropes, or esotropes with approximately aligned eyes and peripheral fusion. Such alignment or partial alignment should already have been taught using dichoptic images as explained in the above sections before attempting this procedure.

With the patient several feet in front of a wall mirror, have him examine the features of his face—nose, eyes, chin, eyebrows. While performing these central observations, most patients will be aware of the details of their faces, not the position of their reflections in the mirror. To expand the patient's sphere of attention and get him into the EDP system, have the patient shift attention to perceive the gestalt of the mirror frame and be aware of how far his reflection is behind the frame and glass. Most patients will instantly see their reflections spring behind the glass.

If when asked to see the frame gestalt, the patient moves his eyes about the frame to view it sequentially rather than simultaneously, the therapist should encourage him to look toward his reflection and see the entire frame simultaneously out of the corner of his eyes. As explained in the gestalt awareness section, he should view the gestalt of the frame just as he would view the gestalt of a business card. This awareness should not be difficult if it has already been worked extensively with dichoptic vectographic and digital images.

If the patient is successful at shifting into the egocentric system, he should see his reflection spring back as far behind the frame and glass as he is standing in front of the mirror. If not, (and the patient's eyes are aligned or approximately aligned) it is likely the patient is still processing centrally (or his eyes are not really aligned). If the patient is not able to expand his sphere of attention out as far as the edge of the mirror frame, have him approach the mirror and place his hands at shoulder width on the glass. Have him wiggle the fingers of both hands simultaneously and be simultaneously aware of both hands' finger movement while watching the reflection of his face behind the mirror. Ask the patient if he can now see his reflection behind the glass of the mirror compared to his hands. This modification allows the patient to open up his sphere of attention less and still shift into the peripheral mode of seeing. Providing that the patient is simultaneously attending to both hands and the reflection of his face rather than sequentially attending to hands and face, he should appreciate EDP.

Another way to open the sphere of attention is to place two strips of masking tape on the mirror, one strip to each side of the patient's reflection. The patient then watches his reflection while being simultaneously aware of both strips. This will often allow the patient to shift into the peripheral mode and perceive EDP. The tapes are especially useful if the patient is practicing using a wide bathroom mirror at home when shaving or applying makeup.

Once the patient has opened his sphere of attention to become aware of the distance his reflection is behind the mirror glass, the therapist can stand behind and to the side of the mirror and have the patient move up or back until the patient's reflection is beside the therapist. To accomplish this, the mirror must either be freestanding or positioned next to a doorway or hall so the therapist can stand in the next room. The therapist then moves closer or farther behind the mirror, and the patient, using EDP, can move closer and farther in front of the mirror to continue to perceive the image of his reflection beside the therapist.

Once good localization has been obtained, the patient can become aware of mirror stereopsis in routine life whenever a mirror is used.

Mirror Near-far Jumps or Mirror Cover/Uncover/Recover

Once the patient has demonstrated accuracy in perceiving the mirror image, the procedure can be combined with near-far jump vergences or cover/uncover/recover. With near far jumps, the patient looks at his finger two or three inches in front of his nose and then looks back into the mirror to locate his image behind the glass. In the case of cover/uncover/recover, the patient covers one eye and imagines that his image is on the glass. (Indeed, most patients looking with one eye covered can image the reflection to be anywhere, either on or behind the glass.) The patient then uncovers the eye, aligns it, and becomes aware of his reflection's correct egocentric position behind the glass. Both cover/uncover/recover and near-far jumps are continued a few minutes at a time over a number of sessions until the procedure is effortless.

Claw Stereopsis

In the movie *Liar Liar*, Jim Carry plays the part of a father who turns his fist into "a claw" and plays a game with his son, chasing him around the room, and warning him to beware of "the claw." These scenes inspire a useful therapy procedure:

> *If you raise your hand with its palm vertical to your face and then curl your fist so your fingers and thumb are all pointed at your eyes, you will be viewing "the claw." If you view this claw first with one eye, then the other, then both, you will see that each eye perceives a different image and when both eyes are opened simultaneously these two different images are combined into a stereoscopic perception in which the fingers appear longer as they perceptually spring out closer to your face. This I call, "Claw Stereopsis."*
>
> *If the patient places "the claw" in front of his face, directs both eyes at the nearest fingertip, becomes aware of how far that fingertip is in front of his nose, and extends his vision to simultaneously be aware of the length of the fingers and position of his palm, the stereopsis will become even more apparent.*
>
> *Just as a wall mirror can provide a stereo target to give feedback for alignment in distance, "the claw" can provide a natural stereo target to encourage alignment at near. The claw can be combined with near-far jump vergences, using the mirror in the distance and the claw at near. An esotrope can similarly use claw stereopsis by holding his curled fist within his centration range to compare one-eyed and two-eyed depth perception.*

Yoked Prism Walk

Yoked prisms are a powerful tool for building EDP. Mismatching eye and body information, yoked prisms often bypass habitual, automatic patterns of perception and trigger exploration. The patient's attention shifts to answer two questions: 1) "Where is my body compared to the world?" (2) "Where is the world compared to my body?" Answering these questions can enhance both egocentric awareness and simultaneous perception of peripheral space. This is true whether or not the patient is strabismic. Getzell has discussed the expansion of the sphere of attention (although under a different name) in non-strabismic patients.[34]

Once the patient has learned to voluntarily align his eyes, or align them enough to allow a peripheral fusion lock, the yoked prism procedure is especially useful as a bridge to egocentric awareness during natural seeing. The therapist positions the patient at the end of a room and has him look across the room and describe what is seen. If the patient is in the central mode, he will likely mention windows, chairs, tables, cabinets, words on a poster, etc. If he is in the egocentric mode, he may say something like "a long room" or "a big room." Thus in the central, sequential mode, the patient sees the particulars of the stuff in the room. In the egocentric, simultaneous mode, the patient sees a room, with stuff in it, the stuff all seen as one with its position in the room.

Once the patient has observed the room, he dons the 15-20 ^ yoked prism glasses base down. The therapist asks the patient to look to the end of the room and try to see the entire length of the floor simultaneously—the patient is thus coached to develop gestalt awareness of the floor the same way he previously developed gestalt awareness of the projected vectograph silver screen, or gestalt awareness of the rectangular edge of the 3D television screen, or gestalt awareness of the rectangular edge of the wall mirror.

Once the patient has simultaneous gestalt awareness the full length of the floor, the therapist asks whether the floor appears to be slanting upwards or downwards. If the patient is in the egocentric mode, the floor will appear to be slanting upwards. If the patient is in the central mode, the floor may appear to be level or floating downwards. In either case, the therapist has the patient walk the length of the room, encouraging the patient to note how much of the room he can see at one time, if things look taller or shorter, if he feels taller or shorter, if things are consistently warped or unevenly warped, some areas being constricted, some being expanded. The patient might note how the room changes if he nods his head, how it feels to walk, if he can simultaneously perceive the two sides of the room or simultaneously behold the floor and the ceiling. The therapist encourages the patient to note anything that might extrovert him into the room and shift him into the egocentric system. Again the therapist can ask if the length of the floor, simultaneously viewed, seems to be slanting up or down.

The patient walks the length of the room and back. The therapist then adjusts the yoked prisms to base up. Now, if the patient is in the egocentric system rather than the central system, when he looks to the end of the room and achieves gestalt awareness of the entire length of the floor, the floor should appear to slant downward. The patient's walking to the end of the room and back, and the questions directing attention are repeated.

With the patient again standing at the end of the room, as at the beginning of the exercise, the therapist again removes the patient's yoked prisms and asks the patient to examine the room and perceive if the room looks any different. If necessary, the therapist can prompt the patient, "Does it seem as if you are seeing the entire room at the same time? Most patients will have shifted into the egocentric system to experience simultaneous perception of the full room and will now be seeing, rather than individual things in the room, a room with things in it, each thing having its individual position in the larger room.

Free Space Egocentric Stereopsis

After the patient has used both vectographic and digital dichoptic images voluntarily to shift between central and egocentric seeing as described in previous sections of this paper, and after the patient has walked with the yoked prism and experienced the perceptual shift into egocentric seeing, the skill can be transferred to natural seeing.

While the patient is standing at one end of the room, the therapist stands half a dozen feet in front of the patient and has the patient direct attention at the therapist's nose, eyebrows, etc. to get the patient into the central mode. Then the therapist asks the patient instead to be aware of the space in between the patient's nose and the therapist's face and also to be aware of the rest of the room behind the therapist. (Again, seeing space is not to be confused with calculating distance, comparing it to a picture of a ruler in the mind.) At this point in therapy, after the patient has already experienced opening and closing the sphere of awareness, the patient should be aware of the shift of perspective, which comes when shifting into the where-is-it, egocentric, peripheral, and simultaneous system from the central, what is it, sequential system. The patient should now be aware of the whole room simultaneously, rather than just observing the details of the therapist's face. The patient, if asked, should be aware that the therapist has a position in the larger room. If the therapist moves, the patient should be able to perceive that the therapist's position in the room changes, being one third or one half the way across the room. Again, if the patient's eyes are darting about the room, the therapist should remind the patient to look toward the therapist and to be simultaneously aware of the rest of the room.

The goal of the procedure is to enable a patient to, at any time, be able to think about the gestalt of space between his nose and any intermediate or distant object and to shift into the egocentric system. Once this becomes second nature, the patient can use egocentric awareness as a feedback for alignment.

Hallway Stereo

Another tool for evoking egocentric awareness is a hallway. Patients who habitually limit perception to the central, sequential system, enter a hallway and instead of being aware of all the space in the hallway are aware of the exit sign, or a particular doorway or wall ornament. If instead, the patient shifts into the egocentric, simultaneous system, all the air in the hallway becomes the center of simultaneous exploration; the patient should perceive the hallway in perspective, the dimensions of the hallway's end appearing smaller in size than the dimension of the walls, floor and ceiling directly surrounding the patient.

To help with this perceptual shift, the therapist accompanies the patient down the hallway and encourages him to achieve simultaneous gestalt awareness of the full length of the floor, monitoring the patient's eyes for telltale vertical saccades that would signal that the patient is looking at the nearer and farther parts of the floor for sequential processing rather than using the peripheral/egocentric system.

The therapist can encourage the patient to perceive simultaneously the two walls of the hallway and how they appear to flow backwards as the therapist and patient walk. The therapist can encourage the patient to see simultaneously the gestalt of the floor and ceiling. The hallway can be used for the yoked base-up or base-down prism walks as the patient achieves gestalt awareness of the air bounded by the length of walls, floor and ceiling. The goal of this therapy is to remind the patient to have aligned eyes, create peripheral awareness, and shift into the EDP system whenever he enters a hallway.

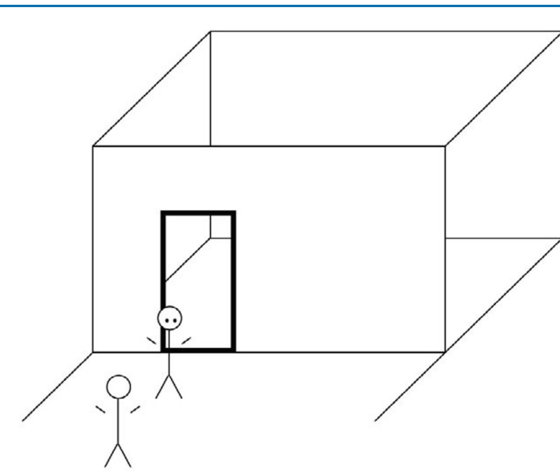

Figure 6—Doorway Stereo

Doorway Stereo

In this activity the therapist serves as a central target framed by a doorway. The room behind the therapist is visible beyond the doorway (see Figure 6). The therapist stands in front of the door frame, facing the patient. First, the therapist encourages the patient to constrict attention to the individual features of the therapist's face. Next, the therapist encourages the patient to be aware of the distance between his nose and the therapist and to see how the wall behind the doorway seems to spring back from the doorway as the room fills with space.

Another way to elicit this 3D perspective is to have the patient open up his side vision to achieve gestalt awareness of the door frame and to see how much space there is between the frame and the far wall in the room beyond the doorway. Again, the goal of the procedure is to teach the patient to shift into the egocentric system whenever he approaches a doorway. The awareness of space can then be used for feedback concerning alignment.

The Shape of the Sky

A blue sky possesses a shape, sometimes bounded merely by the horizon, sometimes chiseled at the edges by mountains, trees, buildings, telephone poles, even launching sites and Ferris wheels. Within, the patches of blue sky are often divided by the fleecy white of clouds or feathered wings of birds. Outside our office, for instance, in one direction the trees cut a v-shaped patch of blue. In the other direction, the trees form a crooked blue figure of sky pierced by a white church steeple. When the therapist coaches the patient to use gestalt awareness to behold the shape of the blue sky, the patient may shift into the egocentric system; the surrounding trees and telephone poles may leap into perspective, each being seen in its proper order of depth.

Thus the gestalt awareness needed to see the shape of the sky affords the strabismic, or other vision therapy patient, with yet another chance for appreciation of EDP to reward the alignment of eyes. Taking advantage of this, the therapist and patient can take a walk outside, the therapist coaching the patient to observe simultaneously the gestalt of the shape of the patches of blue sky and bordering objects and the subsequent improvement in the relative stereopsis. The procedure is complete if whenever the patient walks or drives, he experiences the joy of seeing the shape of the sky, extroverting attention, and enhancing EDP and alignment.

CONCLUSION

Even without touching upon the newest uses of virtual reality,[35] the digital age promises a revolution in the nonsurgical care of strabismus. But what is the goal of such treatment? Most would agree on "aligned eyes with clear, single binocular vision." The meanings of the "clear" and "single" in the goal are fairly straightforward, being almost universally considered in ophthalmic care, even if only crudely approximated to check for neurological integrity. But what exactly does "binocular vision" mean?

Does binocularity mean that when we are placed in artificial conditions using dichoptic images we all see the same illusions, perceptions that occur only in our minds rather than accurately mirroring the world before us? Do we properly perceive first, second, and third degree fusion, physiological diplopia, luster, or rivalry if our eyes are fortuitously aligned with the targets, diplopia if they are not? Or is binocular vision normal only if it allows us—without resorting to sequential processing—to be instantly aware of an object's identity and position in space and to answer the questions "What is it?" and "Where is it?" When we see an object in the room, are we simultaneously aware of that object's position compared to the room and ourselves without the need to assemble the individual features of the scene like pieces in a puzzle, one fixation at a time?

The gift of binocular vision is not necessarily to be found in the numbers and the illusions but in performance and the joy found in the visual consciousness of Barry's "palpable volume of visual space," and Vishwanath's "characteristically vivid impression of tangible solid form, immersive negative space and realness." This paper has offered for the treatment of strabismus some procedures whose success supports Vishwanath's theory of the role of egocentric awareness in the perception of stereopsis.

EDP therapies—and there are many, many approaches, some described for nonstrabismic visual anomalies by Getzell[36]—reward alignment with an awareness of threedimensional space while lessening the stress and discomfort of purely mechanical voluntary alignment. Coaching heightened "gestalt," "egocentric," and "divided" attention extends the "sphere of attention" to allow enhanced EDP and provide an escape from the perturbations of being locked into a central identification system… conceivably evolved to answer the question "Will it eat me?"

In addition to building flexibility of mechanical vergences, therapy should address the localization vergences inspired by EDP. Both vergence modes are helpful in achieving alignment and fusion. This paper has considered one such treatment protocol available to augment the reader's current treatment approach, allowing strabismic and non-strabismic patients alike to thrill at egocentric depth perception.

When this perceptual shift occurs, it can be dramatic, even profound. While the shapes of objects often reduce to little more than reflections of habitual sight, the shape of space is always novel and, like creative visualization, invites a leap into liquid visual consciousness. Exploration and fresh, active seeing in the moment replace habitual, automatic, stimulus-response, stale perception carved by repetitive action, often in a past too distant to recall.

In the words of philosopher Alva Noé, "Consciousness is not something that happens to us. It is something we do or make. Better: it is something we achieve. Consciousness is more like dancing than it is like digestion."[37] When we escape the enchantment of details bound to language by past action, only then are we freed to embrace the silent reality of space. Only then, do we truly begin to dance with the dimensions of the world. Today's digital technologies, added to breakthroughs in our understanding of egocentric depth perception, are making it ever more possible for strabismic patients to see the shape of the sky.

Conflicts of Interest

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