Chapter 2: The Space World

> *He who is insecure in his space world is insecure in his ego.*
> — Skeffington

It never ceases to amaze me how quickly my internal representation of reality comes alive as I open my eyes. My view of the world rushed forth, literally in the blink of an eye, and all the richness of color, texture, line, and contour become apparent. In the previous chapter, "vision" was defined as emerging from four sub-processes: Antigravity (where am I?), Centering (where is it?), Identification (what is it?), and Speech Auditory/Communication. Although much of the neurology that underlies and supports vision can be described with this model, I did not discuss how the individual experiences vision. In this chapter, I'll discuss more about how we experience our lighted world.

Each of us builds an internal representation of reality complete with details gained from all five senses. Scientists and clinicians in many fields, from neurology to psychology, have described vision as the dominant process in the human species. Vision is the process that helps us figure out what is going on around us and how we should react. What is the nature of that internal representation of reality?

How much of what goes on in the world can we take in?

While we are awake and alert, we take a sample of data from the world approximately four to five times a second. Can we use every bit of the energy that stimulates our senses in that quick sample? The answer is a resounding no! First of all, our sensory organs are tuned only to specific bands in the frequency range of the electromagnetic spectrum. Our eyes are sensitive only to a small band of radiant energy between 380 nanometers and 720 nanometers. Our hearing is similarly limited to a very small band of the electromagnetic spectrum. (Fig. 2.1).

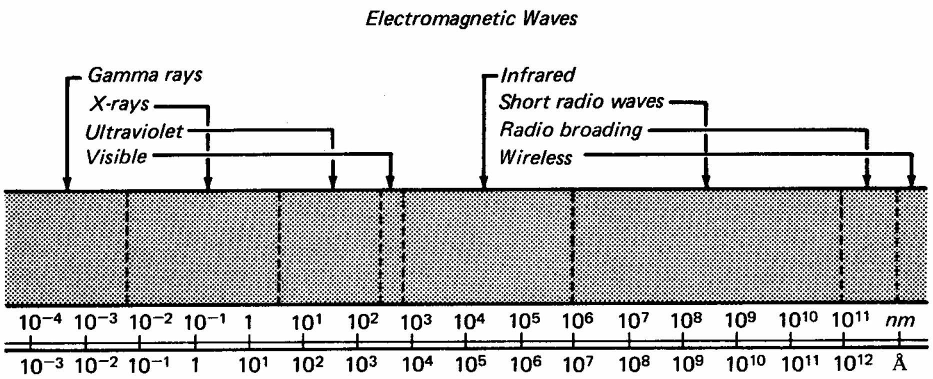

Figure 2.1. This shows the electromagnetic spectrum from the very short gamma rays on the left, to the very long wireless transmissions on the right. Units are in nanometers on the upper scale and in Angstroms on the lower scale.

It is obvious that there is much potential information that our sensory organs are simply not designed to pick up. This is a major filter that impacts all of our perceptions. But the filtering and selection process does not end there. Do we use all the energy to which our sensory array is even capable of responding? Again, the answer is a resounding no!

For example, it is well known that while the eyes are in motion during a saccadic eye movement (shifting in fixation from one position in space to another in a single high speed movement) that stimuli presented during the movement phase go unseen. We only actually "see" when the eyes come to rest. Objects or images that are turned on briefly, and only during the moment that the eyes are actually moving, are not seen. Thus, although our perception seems to be continuous, it is in fact a series of samples of what is going on beyond our physical selves. Events could take place in the time between these samples that would go entirely unnoticed. Fortunately, it appears that most events that have meaning for us occur in a time scale long enough to allow us to see them. However, how often do we hear after an automobile accident, "*I never saw him*" or "*I don't know where she came from*"?

Donald Hoffman states that "Vision is not merely a matter of passive perception, it is an intelligent process of active construction. What you see is, invariably, what your visual intelligence constructs."[4] We as individuals select an area of space from which we sample the current state and use that information to update our representation of reality. That representation of reality is constructed by us and is, as a result, deeply personal.

Let's look at what happens during the actual sampling. It is important to recognize that we have spent our entire life building up a database of experience. We use this catalog of information to give meaning to the world around us. It includes information to help us understand our location in time and space and orientation to other objects. It also includes the vast array of information that has been stored about the particular object that was sampled – for example, how to use and manipulate the object. So, when we take a visual sample of a particular image, we perform a mental check against our database - does it match anything else in the stored database? Does the new information match our expectations, or is it causing some degree of concern that something new is occurring? Without this database of experience, everything would be continuously new and we wouldn't be able to make much sense of it.

It is also interesting to note that there are several levels at which we use our attention to organize the potential information from our outside world. Generally we use mechanisms of attention to sort potential information into several categories. The first and most important to us is the specific information that we have selected to focus on that is important to the current task that we are performing. This data is selected for the finest quality review. For example: Just how far away from me is that car right now? Do I have enough room to…? Is the lane clear to my right so I can move over?

The second distinction, which we make simultaneously, is to determine which information is needed to update the automatic processes that are occurring below a level of conscious awareness but which are on-going evaluations that require a stream of data to remain in the normal state. For example, while driving a car it is important to keep one's car correctly positioned laterally in the lane. For all but the most inexperienced drivers, this isn't something that requires direct attention – it is a process that is occurring below our level of conscious awareness. In some situations these normal, below the level of conscious awareness processes encounter something unexpected, and the previously unattended task needs our attention. At that moment this process now moves to the fore of conscious awareness. Continuing the driving example above, the lateral position in the lane monitoring system might require conscious control if one is driving on a rainy night down a narrow, one-lane highway, with a concrete barrier on one side, and a tractor trailer on the other side..

Additionally, mechanisms of attention may completely fail to acquire some aspects of what is occurring in the physical world. They go unnoticed at both a conscious and subconscious level. This potential information is simply unused.

When we select an area of space from which to derive meaning and direct action, the signal that we feel is important is amplified, and the signal that we feel is unimportant is diminished. What purpose does this amplification serve? The act of attending to something activates the internal neural amplification systems. These systems function to increase the relevancy of a particular object or objects. Some real objects that are observed are only done so fleetingly. The amplification system can help sustain the "image" of that object or objects for a longer period of time. It does this through a process that is built into the neurology called reentrancy (or reentrant loops). Loops exist in the neurology that allow for information further down the line from the sense organs (eyes, ears, etc.) to shuttle information back to the beginning stages of the system so that the same data is enters again. Thus, the image of the fleeting object is amplified not only in its signal strength but in the duration of time that it seems to persist in the mind's eye. These complex reentrant wiring loops exist in nearly all areas of the brain.

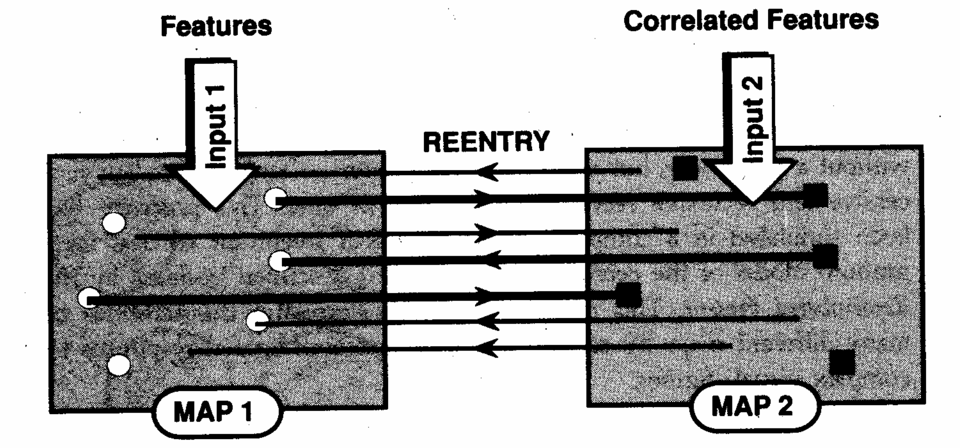

Figure 2.2. Reentry. Two maps of neuronal groups receive independent inputs (1 and 2). Each map is functionally segregated; that is, map 1 responds to local features that are different from those to which map 2 responds. The two maps are connected by nerve fibers that carry reentrant signals between them. These fibers are numerous and dense and serve to "map the maps" to each other.

Is the potential information from the background ignored or suppressed? It is not. At that moment, it is something we are not conscious of. *Figure* is the part of the sensory array that a person is aware of or is thinking about. *Ground* is everything else that the person is not conscious of, but which is available to the person at lower levels of consciousness. Without a stable ground from which the figure can emerge, a figure would exist separate from the things around it. It would not be anchored to a particular point in space relative to anything else and especially not to the egocentric locus [1]of the person doing the looking. Reentrant loops allow us to build stable figure ground relationships. They help establish the difference between figure and ground by amplifying the important parts of a scene. The amplified parts then become the figure in a scene – the important parts of a view that we consciously attend to. Since we cannot possibly attend to everything going on in our sensory field at one time, reentrant loops help define what is important, and magnify those details for us. As an example, think of the first time you noticed a specific make or model of car. Perhaps you were test driving one, or a friend bought one. It was a car that you never noticed before. But after having your attention brought to it once, you start noticing it frequently – on the road, driving next to you, etc. These cars were most definitely there before – but you never "saw" them. What changed? The car now has significance to you, and when the image of that car shows up in your field of vision, reentrant loops serve to amplify the signal, bringing it out of the subconscious ground and making it part of the conscious figure.

When fixating on an object, we can refer to the object as "it." Without knowing where "it" is, how would the person know how big "it" is? There is strong evidence that we do not use retinal angle (how much of the retina does the light from the object occupy) in isolation to figure out how far away or how big something is. For example, a light at the top of a tall skyscraper seen from a quarter of a mile away strikes only a small area of the retina. Our thumb, seen at the distance of one inch, covers nearly all of our useable visual field. However, we don't perceive the thumb as being bigger than the building.

A simple demonstration using afterimages can show how we perceive objects to be totally different sizes even when they occupy the same visual angle on the retina. To perform this experiment on yourself you will need a camera flash light. Look at the square shown in Figure 2.3 and then flash the light (just once) on the page while looking directly at the square. You should now have an afterimage of the square imprinted on your retina. If you hold up your hand and blink your eyes (the blinking will make the afterimage easier to see), you should see that the square fits easily within the boundary of your hand. Now look away at a wall that is far away from you. How big do you perceive it now? It should appear very large. Why? Because of something very simple called *size constancy*.

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[1] The egocentric locus is the point from which a person feels they look at the world from.

Figure 2.3. Use this box for the afterimage demonstration discussed in the text.

The size of the afterimage is fixed on your retina. When you look at your hand, your brain decides that if the object was coming from that distance, it must be relatively small. When you look at the wall, which is far away, your brain decides that if the object were actually that far away from you it must be huge in order to be taking up that much of your retina.

So, thus far, we've determined that a large amount of the energy that has potential information for us goes unheeded because our senses are not synchronized to those frequencies. We've noted that our neurology is not capable of reacting in a fully "analog", or constant manner but rather in a "digital," discontinuous manner. In addition, only relatively small portions of what we actually take in are selected for amplification to become objects of which we become conscious. Amazingly, however, the internal representation of reality that we build appears to us to be complete, solid, and continuous.

Interesting as well is the direction of action in the above scenario. *We* build the representation of reality. *We* select an area of space from which we derive meaning and direct action. *We* use our attention mechanisms to select those areas and objects that get amplified. We do this so that we can successfully perform the actions needed to lead our lives. We go out and get information. There is no information in the light or sound energy. Light in and of itself has no meaning. We give it meaning based on the patterns and changes in those patterns that occur over time. Vision, and all that it entails, is a very active process. The distribution of energy around us, and how we interact with that distribution of energy over time and through space, determines whether or not we will successfully navigate – literally and figuratively – through life's challenges.

Thus, a person actively obtains information or data from his sensory systems that he uses to build an understanding from which to direct his actions. A major role of the visual process is as the means through which spatial representations and inferences are made.

By its very nature, our representation of reality is incomplete. Bruce Wolff, former Chief Educator at the Skeffington & Alexander National Optometric Educational Learning Center, has stated that "most visual problems are problems of omission, not commission." At one level, this can be understood to mean that the person's internal representation of reality at any one point in time cannot include every detail of every thing within the person's visual, auditory, olfactory, gustatory and kinesthetic fields. The person's attentive capability affects his or her ability to take in and prioritize the data from the environment as relevant or not to the task at hand. Because of the limits of the system itself, there will always be things going on that, under different circumstances, could have been seen, heard, tasted, felt, or smelled, but were not.

Are Spatial Judgments Always Accurate?

The Phoria Test

Just after I completed my formal education as an optometrist, I viewed the internal representation system as a fairly rigid structure. Optometrists perform what is called a *phoria* test. Phoria testing can be done in a number of different ways. All phoria tests share some method for separating the view of the world as seen by one eye from the view as seen by the other. Prisms, mirrors, colored filters, or Polaroid filters can all be used to achieve the proper conditions for observing a phoria. The most common phoria test uses prisms (lenses that alter the directional and spatial components of the light that passes through them). The prisms are set up so that the subject sees two images of the same object, one above another, although not necessarily aligned (which is the case for most people - when a simple vertical prism is placed before one eye, the images will not appear to be absolutely straight one above another.). This is called vertical splitting. Another prism, the measuring prism, is then adjusted to the appropriate amount and direction so as to bring about a vertical alignment of the two images. Few people when vertically disassociated keep the two objects exactly aligned; in most instances one of the two images floats to the left or right of the other in varying amounts. The measuring prism will be either base-in or base-out.

If a base-out prism must be used to bring about vertical alignment of the two targets, then the subject is focusing her eyes at a point in space closer to her than the objects' true location—that is, at a point between herself and the objects. The use of a base-in prism indicates that the subject is pointing her eyes to a place in space beyond the target. The higher the degree of prism used, the greater the distance between the objects' true location and the point in space to which the subject is directing her eyes.

The general term for such a misalignment is *phoria*. The prefix "*eso*" is used when base-out prism is needed to bring about alignment. The prefix "*exo*" is used when base-in prism is necessary to bring about alignment.

In performing these phoria tests, I learned that we direct our actions to where we think things are in space. At this point in my professional development, I believed that if the subject was measured as esophoric during these phoria measures, it meant that he judged space to be closer to him than it was in reality. The greater the phoria measured, the more "off" the visual performance will be. Could this simple test, then, explain the basketball player who always seemed to come up short in a pressure situation and hit the front of the rim?

Soon after graduation, I learned that I could get one set of measures in a device called a refractor (phoropter) and another set with a different device that supposedly more closely resembled "real life."[2] The phoria testing that I had thought was so stable was in fact, quite variable and dependent on outside circumstances. Some of the "real life" tests optometrists performed were done in very different conditions than I had learned were appropriate. The tests included the use of a Brock string, a Cheiroscope, and a Van Orden star.

The Brock String

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[2] The phoropter is the instrument used to test a person's vision. The patient sits in a testing chair and a big instrument with many dials and lots of different lenses and prisms is placed in front of the patient. The general term for this instrument is a refractor. Phoropter was the name given to some of the first of these units made in the United States by Bausch & Lomb.)

The Brock string is simply a moderate length piece of string, preferably about 10 feet long, with beads on it. The far end of the string is affixed to a wall just below eye level, and the string is pulled taut, with the other end held at the bridge of the patient's nose (see Fig. 2.4). The beads can be slid to any point on the string, but in this activity the beads should be placed at approximately even intervals on the length of the string. The patient is instructed to look at the various beads on the string or at the very end of the string. Each eye has its own view of the string from its unique viewpoint. Rather than assembling this together to see a single string, most people with good binocular systems see two strings that touch or cross at the point where they are looking.

Figure 2.4. The Brock String shown here is 10 feet long and has 6 beads on it. This one is attached to a pencil to make it easier to hold for long periods of time. The subject views the string with both eyes and, when she is using both eyes together properly, will see two strings crossing or intersecting at the exact location that she has directed her visual attention to. At times she may see the string meeting at a point closer to or farther away from the place she is looking. These misalignments are the basis for performance difficulties in space. We direct our actions to where we place our eyes in space, which may or may not match where the object truly is.

The significant findings occur when there is a discrepancy between where the person says he is looking and where he sees the strings cross. At times the person will report that the strings appear to meet, touch, or cross directly at a bead, in front of a bead, or beyond a bead. When the strings appear to cross closer to the person than the bead he's looking at, the situation is analogous to the *eso*phoria defined above. When the strings appear to cross beyond the bead he's looking at, there is said to be an *exo*phoria.

I had been aware of many times when there was a discrepancy between the results from phoria testing (done in the testing chair in a dark room with a phoropter) and the findings from the Brock string test. I found that the performance-related tests (the Brock string, for example), were more like what a person did in real life situations, making this type of test a much more reliable indicator of exo- or eso- performance. The phoria tests were artificial and offered little that directly correlates to anything absolute.

Over time I pondered and discussed at length with colleagues the question, "What is a phoria?” Over many hours of dialogue it became evident that with a particular patient, one could make the measure of a phoria just about anything simply by altering the targets, lighting conditions, and instructions given. For example, harsh light, very small, high-contrast targets, and instructing the patient to look hard and keep the targets clear will generally increase the amount of esophoria measured. If you use low light levels, blurry targets and tell the person to relax while taking the measure, you will usually measure a higher degree of exophoria.

If so many *outside* factors could vary the phoria so much, how many *internal* factors beyond my control — that the patient could change moment to moment without my knowing it— might also be in play?

It then became quite clear to me that phorias do not measure anything absolute or repeatable. Under certain very controlled conditions with just the right patient, the phorias were stable, but this was not what I saw clinically. I had been taught that the phoria was repeatable and that it represented an accurate measure of what a person would do while driving a car, making a golf shot, or reading. My clinical experience and the many hours spent in dialogue with colleagues led me to understand that this was just not the case. Phorias have no direct physiological correlate. At best, phorias can only be used as relative measures or instantaneous measures of spatial judgments at a single point in time, at a single place in space, under the exact conditions that existed only at the moment the finding was taken.

The Science of Spatial Measurement

In statistics, the terms *reliability* and *validity* are used. *Reliability* refers to a measure being repeatable. For a measure to be reliable, you must be able to test it over and over again and get the same measurement. *Validity* refers to whether or not the measurement that has been made has actually measured what was intended. In the case of phorias I was taught that these measures are both reliable and valid. My clinical experience, however, called into question both of these assertions.

Data exist that demonstrates that what one does with a person before taking a phoria measurement affects the subsequent phoria measurement. During the vision examination, optometrists do a series of tests in a standard, repeated manner. In fact the sequence done by each practitioner is repeated over and over so often, in exactly the same way, that some refer to the whole series as a single test. When inter-element influences within parts of the vision exam were studied, it was shown that the elements investigated previously influence what comes next. For example, patients will adapt to prisms placed before their eyes rather rapidly, especially base- out prisms. If they look through a base-out prism for even half a minute, the next sets of measurements will be biased in one direction. This information helps us understand that phorias are only relative. They are not good predictors of what a person will do in space when presented with real life problems to solve, such as how high to throw the ball up in a tennis serve, or jumping over a puddle.

I also noted plenty of paradoxical results (or what I thought was paradoxical at the time). By paradox I mean not just something that didn't fit what I was taught, but actually seemed to be the exact opposite. With my knowledge at the time, I had no conceptual information to help me understand how repeating a phoria measure with different lenses could yield these types of results. I was taught about what is called the accommodative-convergence/accommodation (AC/A) ratio. Simply stated, this concept proposes that there is some neurological linkage between the amount of focus shift that one makes and the relative position of the eyes together.

When looking at real objects we generally move the eyes in closer together (converge) while focusing closer in space (positive accommodation). Early optometric research used repeated phoria measures with different powers of sphere lenses placed before each eye. A target was placed in front of the patient with enough light to see it clearly. The patient was asked to keep the target clear. Different pairs of matched powered lenses were placed in front of the eyes and the resulting phorias were measured. With statistical analysis, what emerged was a relationship that was represented by a ratio. The ratio was the number of units of convergence (prism diopters) changed for every one unit of accommodative change (sphere diopters) made. The limits of the ratio were from 2:1 to 8:1. Thus, in some people, for every +1.00 diopter lens placed before both eyes, a repeated phoria might shift from 2 to 8 diopters outward to more exophoria. The direction was always the same: plus sphere lenses shifted the phoria to more exophoria or less esophoria and minus sphere lenses shifted the phoria to less exophoria or more esophoria. This was pretty close to an absolute as taught. Each person's ratio was thought to be a measured characteristic of that person, and any changes in the AC/A ratio that occurred only did so slowly over time.

Very early in my education I saw some people who violated this model. I would note a certain level of exophoria (relative position in space beyond the object of regard) with one lens in place. I would then increase the amount of plus sphere lenses binocularly and repeat the phoria measurement. The theories stated that the exophoria should get larger, but I found that in a number of people it actually decreased! This went absolutely counter to the concepts I had been taught. I had no frame of reference with which to understand this response. It was acknowledged that this occurred, but it was labeled as a paradoxical response. I have since realized that people use the label "paradox" as a way of explaining away a critical flaw in their thinking and understanding. When one has a different paradigm from which to view the apparently aberrant response and it no longer appears atypical, the flaw in the logic of the old paradigm becomes obvious. But what was the flaw in this situation?

The theory of AC/A was based on statistics from large groups of subjects. The theory was built on a theoretical foundation that understood vision to be a very mechanistic process. This forced the theory to label the types of responses I was seeing clinically, and which they were ignoring, as paradoxical. However, it took me quite a while to learn this lesson.

As a third-year optometry student I had one of these "paradoxical" cases. After finding the patient's potential distance prescription that allowed for 20/20 visual acuity, I measured (with those lenses on the patient) the patient's phoria at 14 diopters of exophoria. I then repeated the phoria, adding +1.00 diopters of sphere power in front of each eye (in addition to the distance lens formula). This time the phoria was 8 diopters of exophoria. I had given my patient the lens that was to make them diverge more and instead they moved in the *opposite* direction. I showed the data I had collected to my professor at the time and he said, "You have made a mistake. Go back and do the tests again." But no matter how many times I redid the tests I got the same "bad" data with this patient. It was only bad data when viewed from the old paradigm. At that time, my thinking and understanding of the visual process wasn't developed enough for me to provide my professor the opportunity to see this data from a different paradigm.

Over time I worked with many other devices, instruments, and probes that gave me more insights, from which I drew better inferences of what people actually do in space. These include the Brock string, Cheiroscopic tracings, Van Orden stars, and board tachistoscope activities and procedures.

Both the Van Orden stars and Cheiroscopic tracings are done using a stereoscopic viewer (Fig. 2.5). The stereoscope uses a plus lens to allow an object to be physically close to the person yet at optical infinity. A prism (usually 10 diopters base out) is also used on each side to displace the images seen by the two eyes. Two pictures are placed on a platform that is 20 cm (approximately 8 inches) from the lenses. A septum functions as a visual barrier so that the right eye cannot see the object placed before the left eye and vice versa.

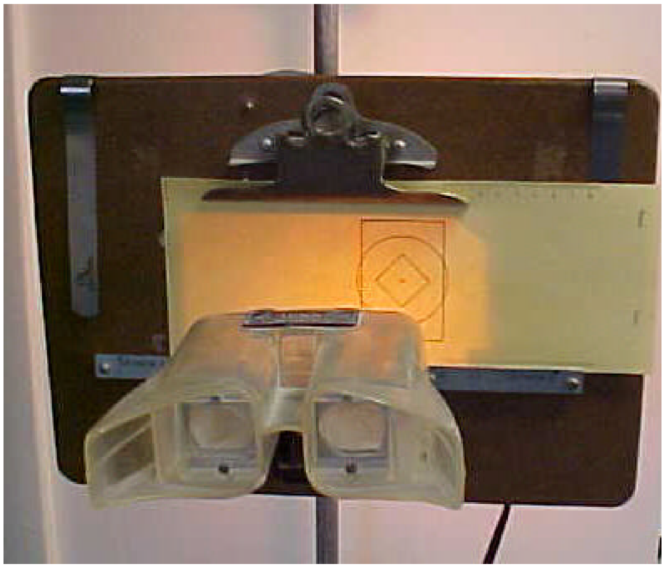

Figure 2.5. This stereoscope was originally purchased from Keystone Corporation and was modified by the author to allow the patient to stand while using it. It can be raised or lowered on the pipe in the back to adjust to children or adults. The Cheiroscopic tracing test target is shown here with the printed picture centered in front of the left eye. The tracing would be done first with the right hand and the right eye viewing the pencil with the left eye viewing the picture.

Cheiroscopic Tracings

For a Cheiroscopic tracing, a simple picture or outline of a picture is presented in front of one eye. Blank paper is placed in front of the other eye and the subject is given a pencil. The subject is instructed to use the pencil with the hand that is on the same side as the blank sheet of paper. (Fig. 2.6). For example, we might place the picture to be traced before the left eye. The right hand is given the pencil and is placed on the platform where the blank paper is located. The eye that the person uses to see the picture cannot see the pencil because of the septum. Similarly, the other eye sees only the pencil and can't see the picture. If the subject has sufficiently developed her abilities to use light from both eyes at the same time (binocularity), she will usually see the pencil and the picture as existing in the same place in space. If so, she traces the picture, making a replica of the picture on the blank paper.

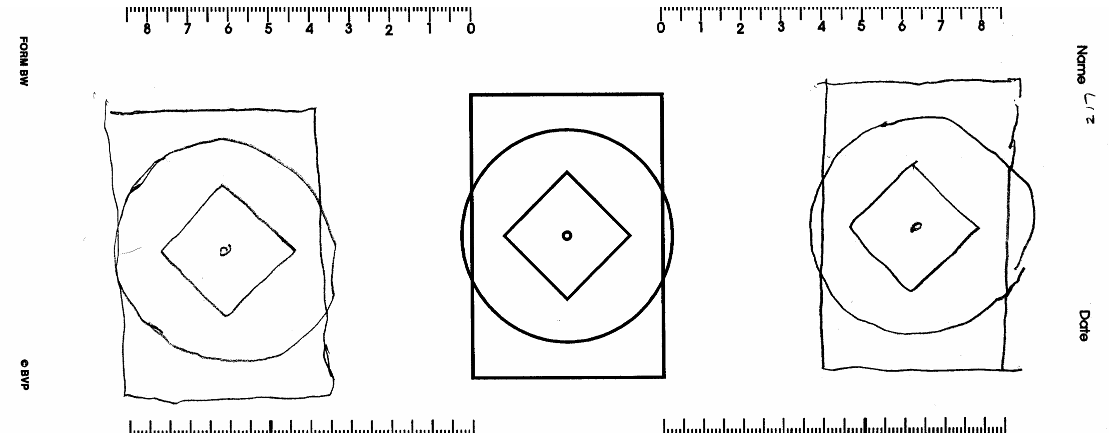

Figure 2.6. A sample Cheiroscopic tracing: The center figure is the model figure to be traced. It is positioned directly before one of the eyes. The other eye has blank paper before it and can see only the pencil. The stereoscope separates the two visual spaces so that the eye that sees the picture cannot see the pencil and the eye that sees the pencil cannot see the picture. The entire figure is traced on one side and then the picture is shifted over before the other eye and the whole thing is repeated. This pattern shows a slight vertical misalignment with the right image projected higher in space than the left. The top portions of the picture are also further out in space than the lower portions.

Because the relative positions of the two spaces are not locked together, the subject is free to place the pencil anywhere and reorganize her view of space to bring about a seemingly perfect alignment. Based on the construction of a particular stereoscope and a given separation of the eyes on the face, an expected degree of separation was determined for that particular instrument. If the tracing of the picture was closer to the actual picture than the actual "zero-point" of that instrument, an esophoria was noted. If the tracing of the picture was further away than the "zero-point" of that instrument, an exophoria was noted. The greater the degrees of shift from the zero-point of the instrument, the bigger the misalignment.

This type of apparatus also gives insight into other types of spatial shifts or changes. The person may have drawn the images out of vertical alignment. When one image is drawn higher or lower than the original picture, it represents a vertical shift. In small degrees, this is typically compensated for with small head tilts. Some people draw the image on one side overly large and on the other overly small. This would indicate that they see the world in different sizes through each channel. You could imagine how hard it would be for a person with this difficulty to integrate these two views of the world. Small degrees of size differences between the two eyes are called aniseikonia. Some eye care practitioners have treated small amounts of size differences, usually between 2% and 6%, with specially designed size lenses. *Size lenses* have differential magnification powers and can be used to match the image sizes of the two channels. Size lenses are produced by varying the curvatures of the lenses and changing lens thickness to achieve the right amount of magnification or reduction.

Many people have poor stability between the two channels and as a result, the tracing they make may only slightly resemble the picture they attempted to trace. Many other changes have been noted and analyzed in great detail by various authors and clinicians. Depending on the conceptual model of the author or presenter, these findings were given different levels of importance in diagnosing and treating visual conditions and led to a greater understanding of what was really going on with the representation of space within a particular person at a specific point in time.

The Van Orden Star

Millard Van Orden, one of the pioneers of the field, used the same type of stereoscope described above and worked with targets that consist of a series of markings on the outside edge of each of the pictures presented to each eye. Some representations of these have used numbers, letters or symbols. Figure 2.7 is a standard Van Orden star target used for diagnostic purposes. Other forms of this target are used primarily for treatment purposes and place one or two circles before each eye. These circles provide the opportunity for the subject to organize the space differently. These forms of the Van Orden star often help the person get the feel of using his or her eyes in a more coordinated or “straighter” manner.

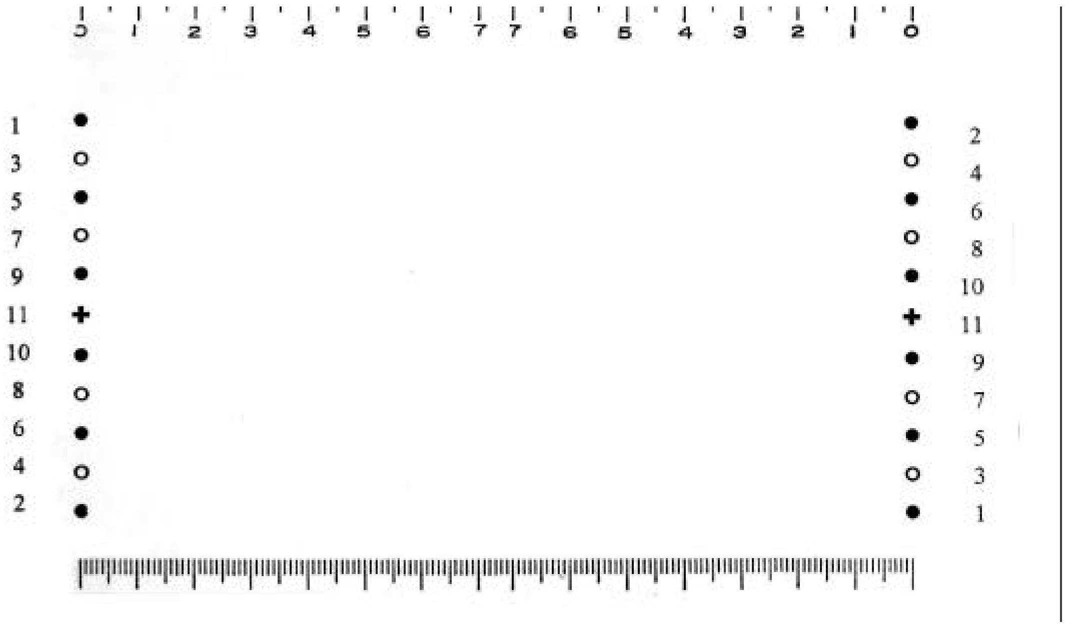

Figure 2.7. Above is an unused Van Orden star form. This form is available from the Behavioral Vision Project, which designed and printed this version. The numbers next to each symbol have been added to show the order that the lines are drawn by the patient.

The subject is instructed to look into the instrument and is given two pencils, one in each hand. The subject is instructed to position one pencil on the top symbol on the appropriate side, and the other pencil on the bottom symbol on its respective side. The subject is then instructed to look in the center of the total space and to bring the pencils together until it looks like they are touching at the middle of the page. After doing this, the subject is instructed to continue in this fashion, drawing lines from each of the remaining symbols to the center of the paper. Different practitioners have preferences regarding the order of completing the lines from the symbols. I prefer to alternate, working from the outside symbols towards the center. If the right hand began on the lowest figure, it would move to the uppermost symbol, followed then by the lowest symbol not yet completed (the second lowest symbol). The final lines to be drawn will start from the center figures on each side. Figure 2.8 is a completed Van Orden star pattern.

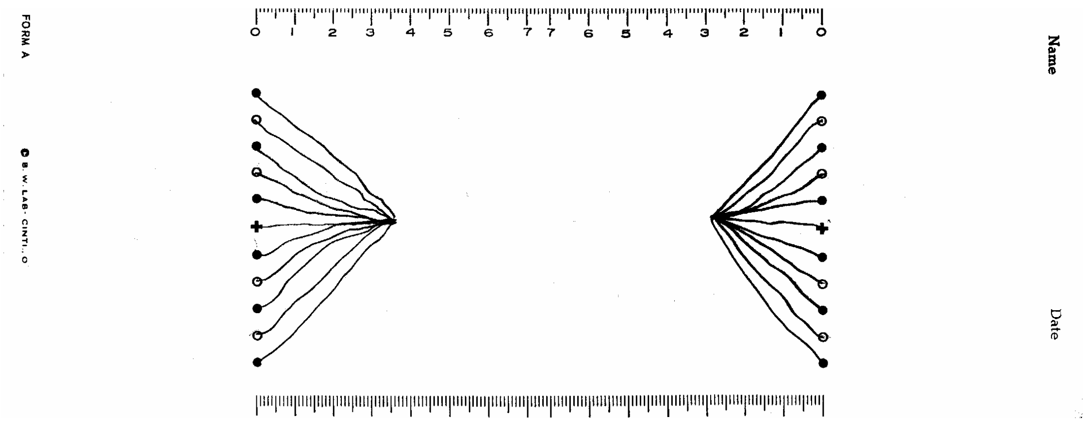

Figure 2.8. Pictured is a Van Orden star pattern done by a patient. Notice how the left side extends further into the center than does the pattern drawn by the patient from the right side. This asymmetry may reveal itself in the person making errors in spatial judgments laterally directing action further to the right in space than the actual object is. On a conscious basis the same person may know that they miss this way and may actually overcorrect leftward at times.

Once again, based on the instrument and the separation of the person's eyes, there is an expected amount of separation between the two points of the "star". Points too close together show an esophoric or too-close-in-space posture of the eyes. Points too far apart show an exophoric or too-far-in-space posture of the eyes. Much more has been written about the interpretation of these drawings, but this explanation is sufficient for our purposes here (see Fig. 2.9).

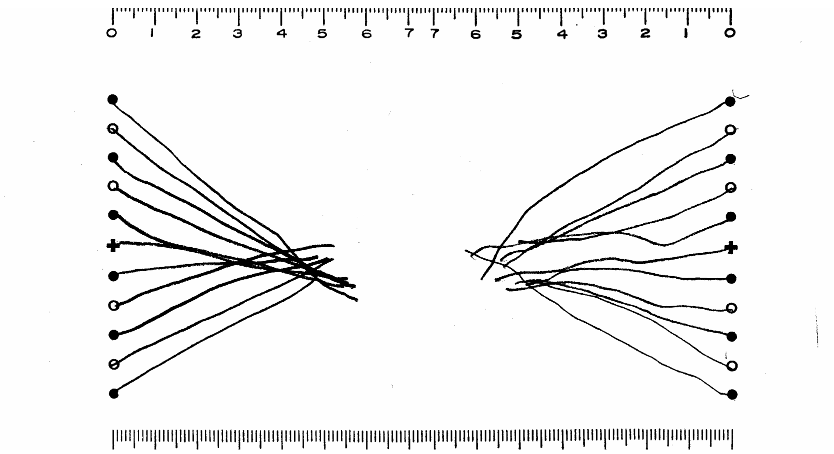

Figure 2.9. This Van Orden star tracing shows a number of things. The first thing that can be seen is that the lines go to a point nearer the center from both sides than in the previous figure. This shows an eso- or inward-directed movement pattern. Second, the pattern is not as well organized. As this person was doing the procedure, they changed how they were looking at it and drew lines to different places. All were drawn to a point closer than the plane of the stereoscope but to different points as the patient continued to draw. The left side appears a bit more organized than the right. *Organized* is used here to mean a more static structuring of space which would be indicated by the lines coming to the same point.

A grouping of lines intersecting closer to a point would be classified as more organized. A grouping of line that intersects only in a region or area are less organized.

The Board Tachistoscope

I was introduced to the board tachistoscope by members of the Behavioral Vision Project as a part of an on-going study group begun as part of the Skeffington Alexander National Optometric Education and Learning Center. In this procedure, the person stands or sits in front of a large chalkboard or marker board. A simple figure such as a square or the letter E is flashed quickly (usually 1/100 of a second, but the duration may be varied considerably on many devices) on the board by the tachistoscope. The time of presentation is too brief for the person to scan the picture. It must be taken in as a whole. The person is then asked to draw the figure on the board in the exact size and location that the projected image was presented. This is done a number of times with different simple figures. Over a series of presentations, certain personal trends become evident. A person may make all the drawings too small or all too large or all to the right or all too high. These systematic shifts or transformations give insight into the distortions of the person's own internal representation of space.

Topological Transformations

At about the same time in my professional development I became aware of a number of scientific researchers who had as a goal the quantification of human visual performance. Their research was based on some basic assumptions about vision that had been made many years ago, but many were still working on this goal at the time of my studies. They wanted to reduce this elegant process to a number or a series of numbers. In order to apply the high level statistics they were using to "prove" things, they made several fundamental assumptions. One underlying assumption was that the scales used in optometry were equal interval scales. It was assumed that for any given person, the difference between 20 and 22 diopters of convergence was the same as that between 0 and 2 diopters of convergence. The difference between -0.50 and -1.00 of spherical lens power did the same for the person as the difference between –4.00 and –4.50. Because the scales appeared on the testing apparatus to be equal-interval scales, the researchers decided it was valid to use the more powerful statistical analysis equations that equal-interval scales permit. It is this exact assumption upon which the conventional methods of understanding the data collected in the analytical evaluation are based. One such type of analysis was called *graphical* analysis. Nearly all theories and concepts that rely on AC/A ratios assume the measuring scales used to be equal-interval. These relationships could all be described by simple first-order equations such as:

$$\text{Convergence (prism diopters)} = 4 * \text{accommodation (sphere diopters)}$$

This equation states that by altering the posture in space of the mechanism of accommodation by one diopter of sphere power, the result is a shift in the positioning of the mechanism of accommodation by four prism diopters. As plotted on a graph with each axis being linear, the resultant line shows a stable relationship through the entire range of movement.

Bruce Wolff [5] introduced the concepts of non-linearity from chaos theory to vision in 1988. Wolff made the analogy to topological or topographical types of transformations in which the systems depicted were nonlinear. When I first head this concept of topological transformations, I had no clear idea of what they were or what he was referring to. I heard the word "nonlinear" but I was still thinking linearly. Nearly everything I had been taught up to this point involved linear equations and linear relationships.

These discussions came up in the context of understanding how people developed their internal space world and in what ways their space world did not match the real physical world. The directions of movement of objects that are part of the internal space representation were toward self (centripetal) and away from self (centrifugal). I thought of these as simple linear transformations.

Here is a way that might help you visualize what I was thinking of. Imagine that an artificial three-dimensional cubed grid has been overlaid onto a scene. The separation of the grid lines is an unknown *X* cm between lines. A real object might be 100 grid units of distance away from me. We know that some people have a distorted sense of distance, and that they perceive things as closer than they are in reality. We could say that these people have a perception that the fundamental unit of separation of the grid lines is smaller than reality. Maybe they perceive the X cm as 0.9*X* cm – and in effect see the object as being 10% closer than it actually is. This would be measured as an esophoria. This method of transformation involves a simple linear conversion of the grids – making each box of the grid uniformly smaller. Conceptually, I understood that these transformations did not have to be the same in all areas of space. One part of space could be shifted in, while another could be shifted out. Left space could be constricted inward (0.9*X* cm per grid unit), while right space could be expanded outward (1.1 *X* cm per grid unit). The transformation in upper space could be different that in lower space. I had come a long way but I was still thinking linearly.

At some point, I became aware of the emerging science called chaos. Chaos is many things, but fundamentally, chaos theory states that nearly all assumptions about linear relationships are wrong. The basic physics I had learned were nearly all special-cases that were based on a host of assumptions that do not allow for the real world. As an example you might remember your physics instructor talking about pendulums. They were always described as swinging in a perfect vacuum with a frictionless fulcrum, etc. Well there is no such thing as a perfect vacuum or a frictionless fulcrum. They were constructs used to simplify the discussion but are actually impossibilities in the real world. What emerged - my great personal discovery from this - was an understanding that the perceptual scales that patients reacted to and behaved by were, at best, ordinal. *Ordinal* here is used as it is used in statistics. All that one knows about ordinal scales is that the larger the number the further along the scale it is. Four is more than three but not necessarily the same amount of difference as that between two and one. The measures can be put in order but no higher-level math relationships can or should be made.

As an example, let's look at a person who is nearsighted. The unit of measure of nearsightedness is in spherical diopters. A person might be measured as being four diopters nearsighted. Does the person get as much benefit from the first two units of prescription as the last two units? No. A person who is four diopters nearsighted might note little or no change in her ability to move through the world with two units of prescription. However, add two more units and she will come alive and be able to function as she normally does. It is possible that the first three diopters might help as much as the last one diopter. Although many people measure the same amount of nearsightedness, they can function very differently with varying amounts of prescription.

The concept that our scales are not actually linear, and are in fact ordinal at best, led me to a different understanding of what was meant by topological transformations. These transformations are made nonlinearly, and can vary with direction and distance, even along the same line of sight. Even measures such as the Brock string, Van Orden stars, Cheiroscopic tracings or board tachistoscope still give insights only to what the person is doing in that specific situation at that specific time. These tools are the best we have available at the present time, but they really don't give us insight into the non-linearity of human vision. Board tachistoscopic techniques come closer to looking at these relationships, but even they only investigate one point along the *z*-axis.[3] I suppose that a series of board tachistoscopic readings could be done with the patient at different distances to enhance the procedure, but even this would be imperfect.

Scaling

Another type of transformation derived from chaos theory has to do with scaling. To demonstrate this, I have played the following mind game. I imagine a finite space, and I must fit the things that I am thinking about into this space. Try this yourself: See if you can picture some of the following things as you read them. After you read about them, close your eyes and try to feel where you are looking when you "look" at the things I have suggested. First, picture the distance between you and the moon. Feel where you are and where your image of the moon is. How far out into the blackness of your visualization are you peering? Between yourself and the moon are a number of divisions that you have created to make sense of your space world. When thinking about large distances, each block or division might represent thousands or hundreds of thousands of miles.

Next, picture an electron orbiting the nucleus of an atom. Place yourself at the nucleus and look towards the electron. Where is the electron in reference to you? How far into the blackness do you look to see the electron? Many people report that they feel they are looking at the same place when they look at either the moon or the electron. There are two different targets, but only one relationship between you and the object. What *has* changed is how we scale the subdivisions. Somehow you and it were the same physical distance apart when it was the moon or it was the electron. The only change was the scale of the space between you and the object.

Scaling should be done fluidly and can change many times within the course of seconds. Think now about how far it is to where you will sleep tonight, where your office is, where Antarctica is, or how far your water glass is from you. Those people who consistently make highly accurate distance (as well as timing and rhythmic) judgments have separated their space representation into very fine subdivisions. The implication is that if there are more subdivisions that are meaningful and significant to how those people operate, then their performance will be more accurate. This helps explain the grace of some actors, athletes, and dancers. It is also the basis for the incredible rhythmic ability of very talented musicians.

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[3] The *x*, *y*, and *z* axis system is a coordinate system used to describe the location in space of any object relative to another. It is a linear system based on a grid of perpendicular axes. X is the horizontal axis, Y the vertical and Z is the axis that runs in and out in space away and towards the person.

Just Noticeable Differences

This brings up a concept that runs through vision and the visual process: that of a "just noticeable difference" (JND). How different must two things be to be recognized as being different? How close do two things need to be for us to perceive them as being the same distance away or occupying the same place in space?

As an example, let's look at the fine JNDs of symphony musicians in their ability to play in tune with each other. If we put 100 people in a room and begin the following experiment, it will become clear that people have varying levels of JNDs in their ability to hear the differences between pitches. Two pitches are presented, one after another. Each person must vote on whether the pitches were the same or different. Sometimes the two pitches are the same, and other times they are different. At the beginning of the experiment, the gap between the pitches that are different is large. (The only change to the sound played is with the pitch. All other parameters remain the same including timbre, volume, duration, attack, decay, etc.) Then, as the test continues, the sounds that are presented as the "not-same" pair are brought closer and closer together in pitch (wavelength). As the experiment continues, it will become increasingly difficult for some people to hear the differences between the two pitches and they will (mistakenly) say that these two different wavelength pitches actually sound the same. Some people will make this mistake while the pitches are still rather far apart. Later in the process there will be only a handful of people who are still hearing the differences. People have different JNDs in just about everything that they encounter. This is one part of what makes each person's view of the world unique. We are all sensitive to subtleties in different aspects of their life based on our life experiences. No two people will have precisely the same constellation of JNDs throughout all aspects of their cumulative experience.

The more experience one has with a particular series of stimuli or life experiences, the greater the probability that they will develop finer JNDs in that aspect of his or her life. However, increased life experience in a particular area is a necessary but not sufficient component for the refinement of JNDs. The important point is that JNDs are developed and are trainable. Of course, there are physiological limits within which the system must work. However, conscious awareness of and the ability to use these subtle differences must be cultivated and developed. It is a *trained* welder who can tell the quality of weld by the color of the metal, and a *trained* musician who can tell the pitch and tuning of his instrument to an incredibly fine degree. These professionals are not born with these abilities. They may have been born with different potentials for development in each of these areas, but both required practice and experience to develop the fine JNDs that mark the true experts in a field.

The Space Board

In the late 1980's, Claude Valenti, an optometrist from La Jolla, CA, demonstrated a simple device used to demonstrate the manner and degree that people misperceive the location of objects in space. Valenti stated that the inspiration for developing his method came from John Streff, an optometrist in practice in Ohio, who had demonstrated a procedure he called "touch points". In the touch point procedure, the practitioner holds a finger vertically in front of the patient from above with the finger pointed down at the floor. The finger is normally placed at eye level although this can be varied. The patient is told to look directly at the finger and then, in a single, fast, ballistic type of movement, move one hand upward to allow the index finger on that hand to attempt to touch the finger of the examiner. It is important that the patient not slow down and adjust after beginning the movement, as the examiner is looking for slight misalignments as the finger approaches the stationary target finger. The misalignments were read as misjudgments of space.

Valenti's procedure was modified extensively. A thin board is mounted on a structure that allows the height of the instrument to be shifted up and down to match the height of the patient. The board projects horizontally from the wall. There is a small cutout on one side for the patient to put their nose into, assuring that the patient remains properly aligned during testing. The patient looks across the board and out into open space rather than at the wall (Fig. 2.10).

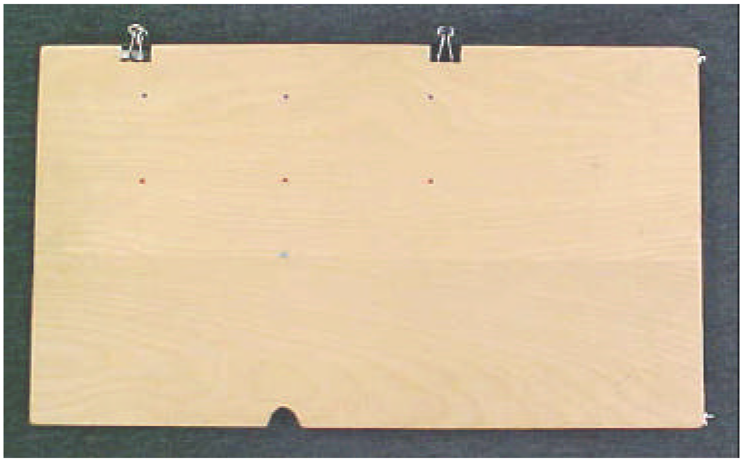

Figure 2.10. This shows the pattern of the pins on the top of the actual space board. The patient stands with their nose in the small cutout at the bottom of the picture. The single pin is closest to the nose and is directly in front of the patient. The pins all fit within the boundary of an 11" x 17" piece of paper. The right side of the board is attached to the wall so that the patient is looking out into the room rather than into the wall.

Seven small-headed pushpins are placed on the top of the board in a predetermined pattern (see Fig. 2.11).

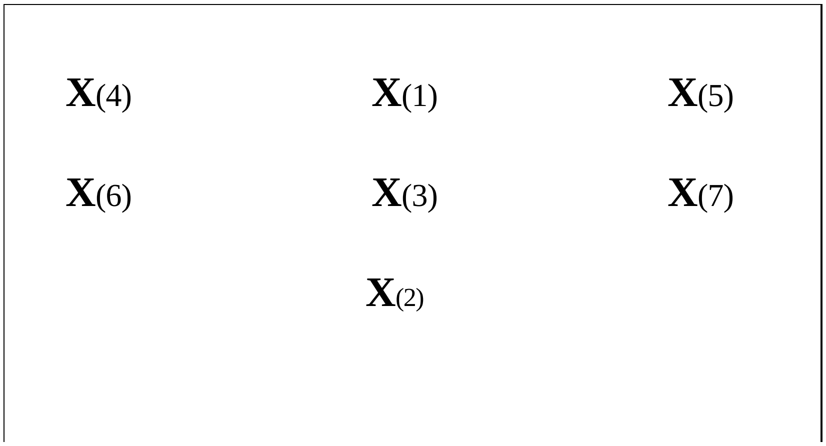

Figure 2.11. This figure shows the sequence that the patient is asked to mark the pins in. The first points are all on the midline. Then the points alternate sides. This is done to reduce the influence that one movement will make on more than one point.

A piece of paper is attached to the underside of the board, pre-marked with the actual pin placements. When the paper is properly attached underneath the board, the markings are directly below the pins that are on the top of the board. The patient then is given a marker to hold in both hands. She cannot see the marker. She stands on both feet, with equal weight on each foot, and with her knees slightly bent. She looks first at the pin on the midline furthest away from her. She is asked to bring the marker up from below and touch where she sees the pin to be. She is directing action in space to where she is looking. This is a very basic request of the visual process. The sequence of how the pins are looked at and touched can be seen in Figure 2.11.

Figure 2.12. This shows the space board in use. The patient's nose is in a small cutout that is directly lined up with the centerline of pins. The recording paper is held onto the bottom of the board in such that the Xs on the paper line up directly with the pins. The patient performs the marking bilaterally with both hands clasped together around the marking pen.

Figures 2.13 through 2.16 are a series of drawings by actual patients; the legends describe each type of topological transformation seen in each situation. Because the paper is on the bottom and is turned over to read the results, right and left are normally reversed. The diagrams here have been flipped over for ease in explanation and interpretation. To help the reader see the patterns on each of the figures lines have been drawn in to connect the actual data points of the patient. If the patient had touched exactly at each of the pin points, the lines drawn would connect each of the Xs. When the line does not touch the corresponding X, there was a mismatch between the actual position of the object in space and the perceived position of the object.

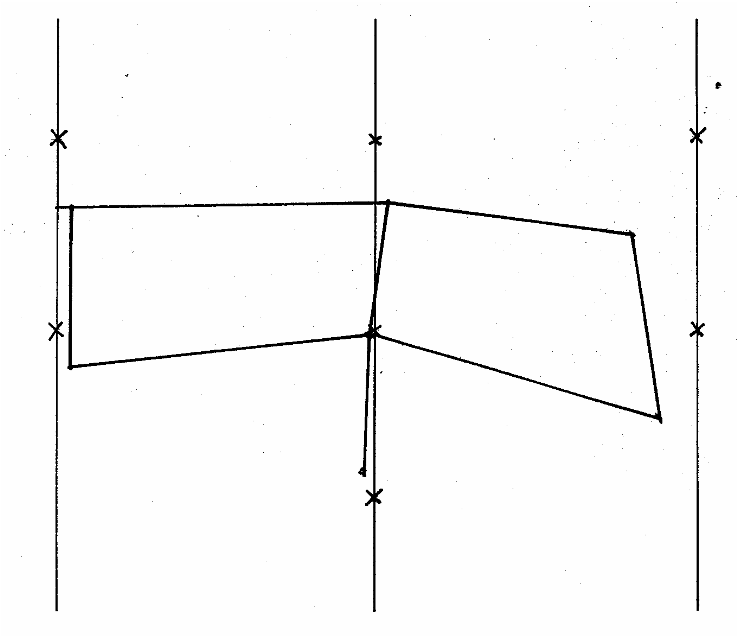

Figure 2.13. Note with this patient that the middle point is almost exactly on target. If this happened to correspond to the point where a phoria measure was taken it would show very good alignment. However, note how the other points are shifted in different directions, with some closer and some farther away.

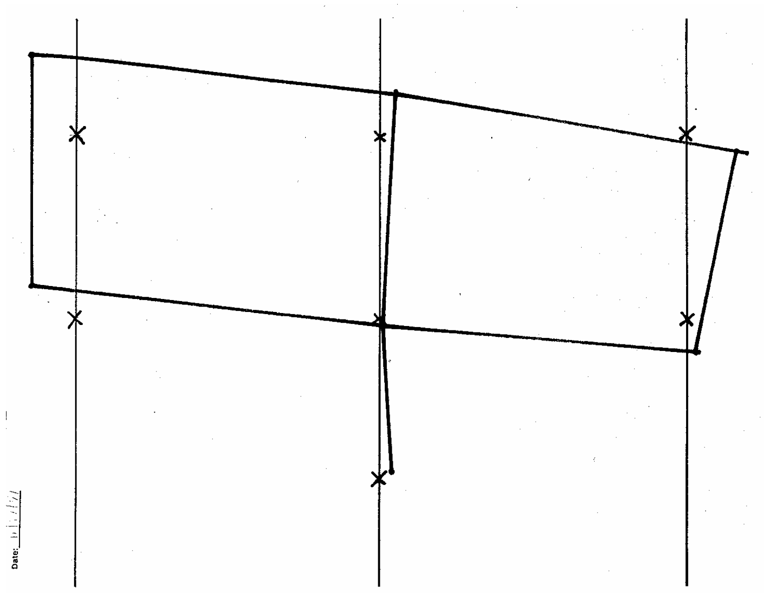

Figure 2.14. Once again this patient has the middle point almost exactly on target. However, notice how the markings on one side are shifted inward toward the person and on the opposite site the pins are shifted outward, away from the patient. This patient happened to be a competitive equestrian rider. She complained about her horse having difficulties with the turns, turning too sharply one way and too wide the other. How surprised she was to find that the problem was hers and not that of the horse!

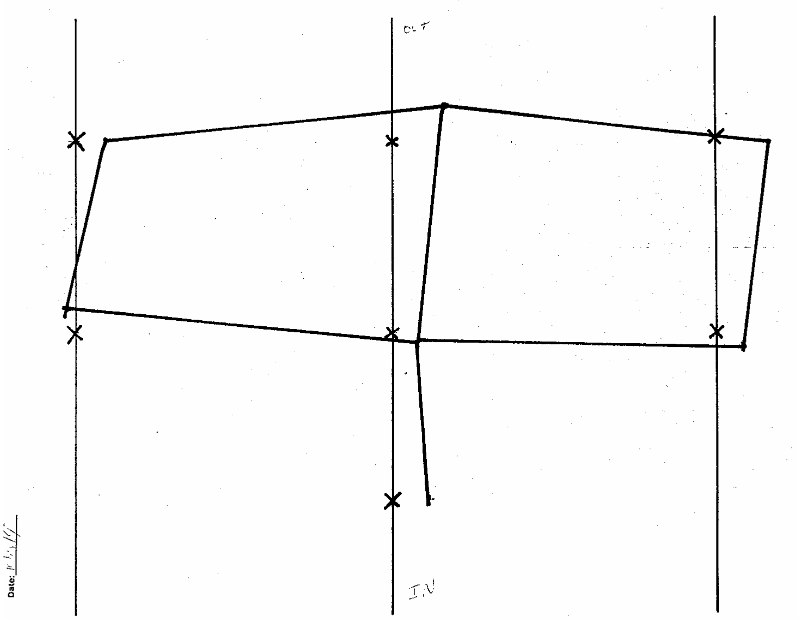

Figure 2.15. This patient shows six of the seven marks being displaced to one side. In cases like this, one often sees an asymmetry in movement and in motor performances such as those involved in sports. Yoked prisms are often investigated as a possible treatment option when this kind of shift is demonstrated.

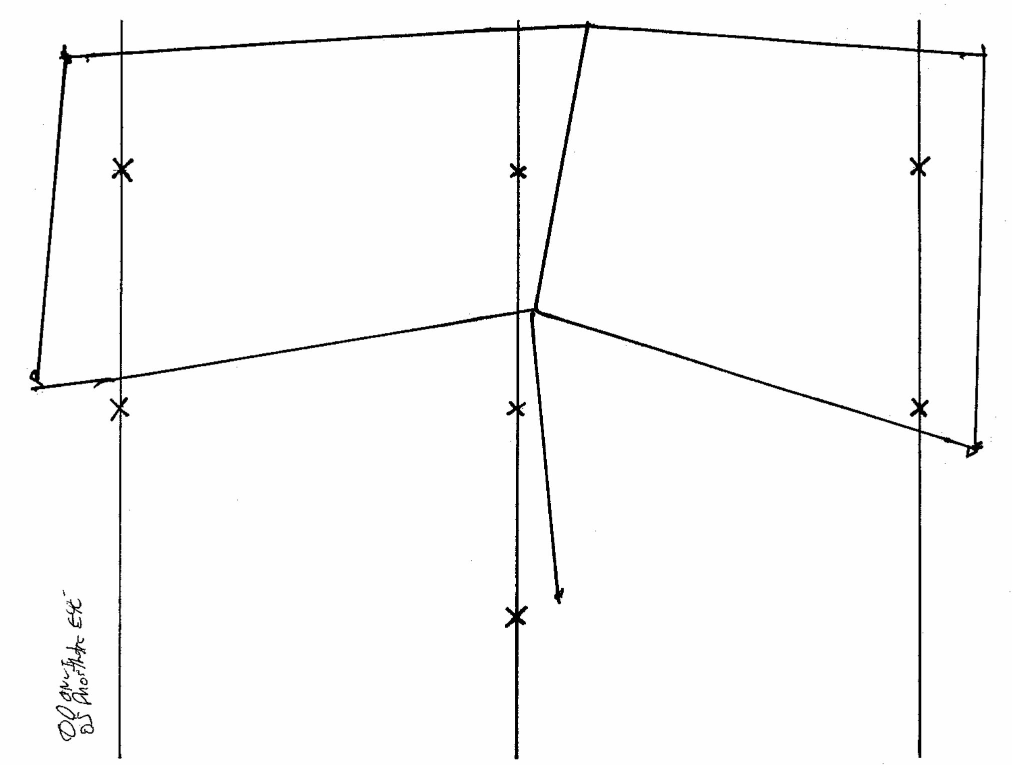

Figure 2.16. In this final example, the patient lost her left eye in a riding accident while on a horse. This drawing was done with her intact right eye. The space board can help give insights into a person's spatial perception when a standard phoria type of measure cannot be taken, since phorias require two eyes.

Using this simple device can help you understand the idea of the internal space representation of reality that each of us makes to help direct action. It has facilitated a better understanding of how to use lenses and prisms to treat different types of problems.

A final note: Our internal representations are not fixed. During the day and from moment to moment the shifts may vary and change. Different levels of stress may result in different patterns. It is believed, however, that there are trends to the spatial shifts and that what is seen in one situation will have some predictive value in other related activities. However, it is recognized that the patterns may be very different in other unrelated types of situations.

The space representation we build within us is critical to how we interact with our world. The completeness and the accuracy with which we do this, determines much of how we interact with our environment. From our internal representations, which are by their very nature incomplete and nonlinearly transformed, we direct our actions.

References:

1. Edelman, GM. *The Remembered Present*. City: Basic Books, 1989.
2. Edelman, GM. *Bright Air, Brilliant Fire: On the Matter of the Mind*. Basic Books, 1992.
3. Jenkins, FA, White, HE. *Fundamentals of Optics*. New York: McGraw-Hill, 1957.
4. Hoffman, Donald D., *Visual Intelligence – How We Create What We See*. WW Norton Company, 1998 ISBN 0-393-04669-9.
5. Wolff, Bruce, "A Window on the Universe", 33rd Skeffington Symposium on Vision, January 23-25, 1988, Arlington, VA.

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