Article: Tactile-Visual Integration and Stereopsis

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"Eyes don't tell people what they see. People tell eyes what to look for."

This quote by Lawrence MacDonald encapsulates why it is that any two people viewing the same image/object do not necessarily *perceive* the same thing.

Patients with weak binocularity have difficulty integrating information from the two different vantage points of their two eyes. This contributes to difficulty appreciating stereopsis (solid-seeing) based on visual input alone. However, motor experiences provide abundant opportunities to conceptualize depth. Therefore, tactile input can be harnessed in the binocularly-deficient patient as a way to support the development of stereopsis.

We all navigate through and interact with a 3-dimensional world, where we are continually encountering solid objects which take up volumes of space. We learn to depend upon feedback from our hands and arms as to the size, weight and texture of objects. We can judge how much force to apply when picking up an object based on its size, volume, material. For example, when picking up a large vase which exceeds the grip of one hand, we will hold it with two hands, so as not to drop it. The hands conform to the curvature of the vase, taking on its shape and dimension. Manipulating the vase provides us with further information about the overall size of the object.

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Now, imagine you are in the process of redecorating. You carefully pick up this large vase, and you gain knowledge of its mass, size, and how much effort you must apply to maintain your two-hand grip. You place the vase on a shelf, out of the way. Later on, you return to move the vase to a new location. Do you pick it up as tentatively as you did the first time you encountered it? Or do you directly and efficiently lift it, move it, and release it, with minimal assessment?

Now let's add a twist: You have been blindfolded. Your task is to arrange a display of three large vases of different sizes on a shelf which is 2 feet deep and 4 feet wide. The vases differ in height, in maximal girth, and in texture. Sight-unseen, you assess all three, and set about to place them on the shelf in a visually-pleasing distribution. As you handle each vase, you are forming a spatial picture in your mind, and you are assessing relationships between the three. Although blindfolded, this is a visual process.[a]

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Take the blindfold off, and you are merely confirming what you already know, what you already have seen in your mind's eye.

Eyes <u>don't</u> tell people what they see…

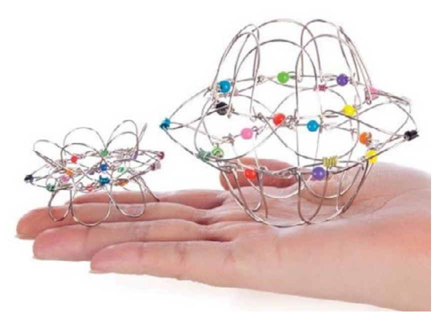
…On the contrary, we scan our environments based on prediction and anticipation. Developmentally, motor assessments of our space-world lead us, until we *transfer* these skills to the visual process, via tactile-visual integration. In time, we learn to predict what an object will feel like, texturally, before we touch it. We predict the size of an object before we reach for it and grasp it, separating our hands by the appropriate distance, and cupping our hands to the appropriate curvature, before we grasp the object. We predict how heavy an object will be before we apply the force to lift it.[b]

In practice, these principles can be applied to the visual-perceptual development and enhancement of stereopsis, particularly when viewing visual image projections, such as *vectograms.*

Stereopsis has a number of quantifiable attributes.[1] Many doctors only assess stereoacuity, which is the smallest detectable z-axis separation of two images. Another quantifiable measure is stereo-volume, which is the largest z-axis separation of two stereoscopic images which can be perceived simultaneously without diplopia. A third aspect of stereopsis, somewhat difficult to quantify, is the amount of *time* it takes for the appreciation of stereopsis. This time-based attribute may be called "stereo-facility." It is interdependent on the patient's fixation disparity, localization accuracy, and the functional volume of space surrounding fixation.[c] For example, a person who can achieve a fine stereoacuity under static conditions in an untimed viewing task may not demonstrate comparable stereoacuity under a time limit, or under dynamic viewing conditions.[d] Thus, they may have poor stereo-facility despite having excellent stereoacuity. As with stereoacuity and stereo-volume, stereo-facility can also be enhanced with practice or guidance.

Telling eyes what to look for…

Wandering through a five-and-dime in New Hampshire, I found a surprisingly useful toy: It's called "Magic Loops," a charming manipulable set of interlacing wires (see Figures). It reminded me of my newly acquired "Gem" vectograms, made by Vision Assessment Corporation, so I bought two of them for about $2 apiece, and I brought them to my Vision Therapy room to experiment.



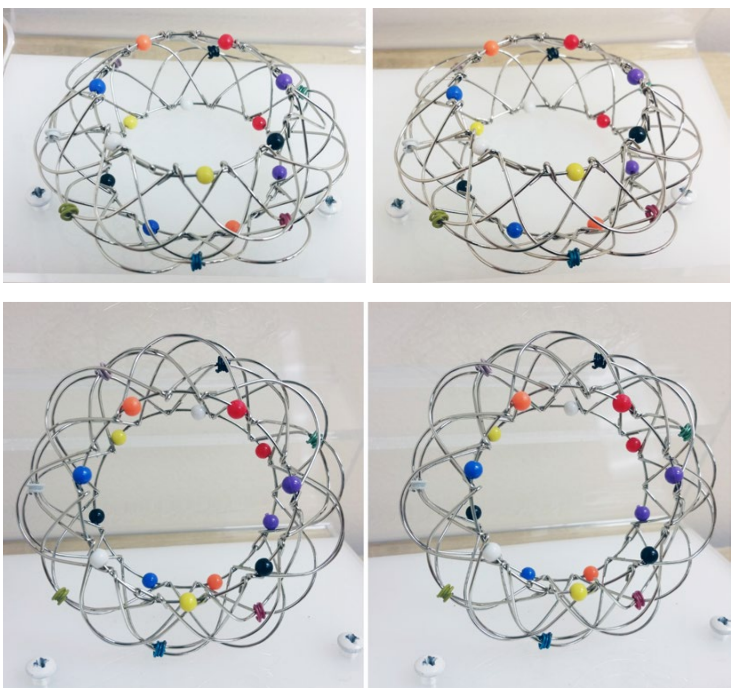
a. This process of visualization varies between people: At one extreme, people can perceive and voluntarily manipulate vivid visual imagery. At the other, people report a sort of intuitive "knowing," which guides them in executing such a task, although they do not become conscious of a visual image.

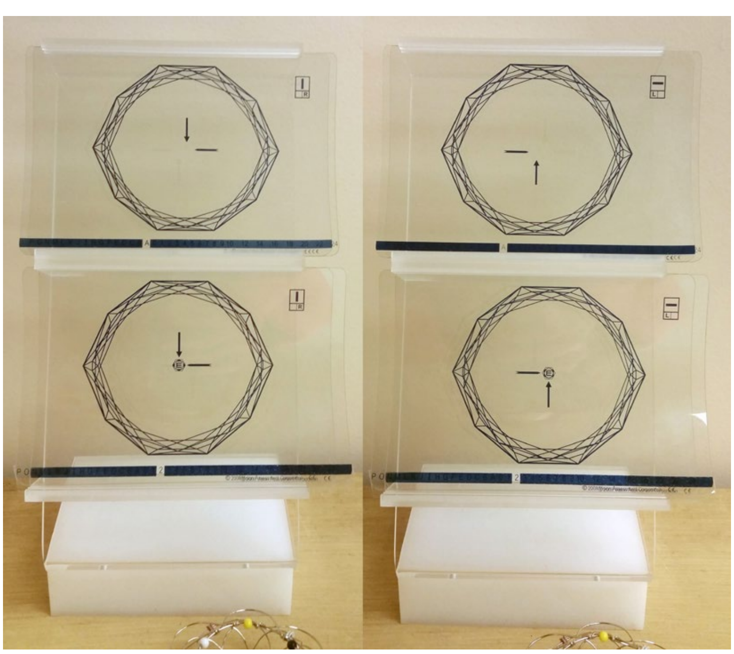
b. In the supplementary video, at 4:49, note the difficulty the patient has in approximating his hands for the purpose of cupping the presented object. This highlights the difficulty he has in visually assessing real objects, let alone the vectogram.

c. The "functional volume of space surrounding fixation" refers to the area of the viewer's visual field which they actively utilize, akin to the measure of functional visual fields (or "color fields"). This may be much more constricted than the same viewer's threshold visual field, which measures the potential of the individual to see at a given foveal eccentricity.

d. Dynamic stereoacuity represents yet another quantifiable measure of stereopsis; it can be assessed with either the object or the viewer in motion. An example of a dynamic measurement would be repeating a threshold acuity test (such as visual acuity or stereoacuity) while the viewer induces the horizontal Vestibular-Ocular Reflex (VOR, shaking the head 'no' while viewing the stable target).

When I first started using the Gem vectograms, I had been delighted by the biofeedback afforded by the Fixation Disparity (FD) lines, both with and without the binocular lock (central E). But I soon came to learn that while many patients could see the Gem float, patients whose binocularity was more compromised got confused by the fine tangles of the Gem. They preferred the familiar shape of the Quoits. Since the Quoits lacked the biofeedback of the FD lines, I continued to experiment with the Gem. The problem was, these patients *did not know what to look for.*





Now, with Magic Loops, I presented a solution: I seated a patient with intermittent exotropia ("MG") in front of two Gem vectograms: On the top track, the Gem with FD only was placed at 1^ Base In (BI, setting 'A'). On the bottom track, the Gem with FD and fusion lock ('E' at the center), was placed at 2^ Base Out (BO, setting '2'). The patient was directed to attend to the lower Gem. She reported fusion, the (bottom) arrow seen by the left eye was wavering, but both arrows stayed close to alignment on the E. I suggested she breathe in, and on the exhale, expand her attention to see the Gem in her peripheral vision. She reported single vision of the Gem, and that it was floating in front of the vectogram holder. Meanwhile, I manipulated the Magic Loops to the same conformation as the Gem, and placed the real object into her hands. I guided her to hold it gently, so that the apex of the toy was between her index finger and middle finger on both hands. The Magic Loops created a spatial separation of her fingers. The angle they created mirrored the angle I perceived in the vectogram. I then guided the patient, "This object has the same exact shape as the Gem. Notice the angled separation of the front side from the back side of the Gem. The part of the Gem which has the largest diameter is in the *middle* of the front and back sides. Now see if you can appreciate the solid shape of the Gem in the vectogram…"

Within moments, MG's eyes widened: "Oh my G-d, I see it! I see it!"

"And the arrows?" I prompted.

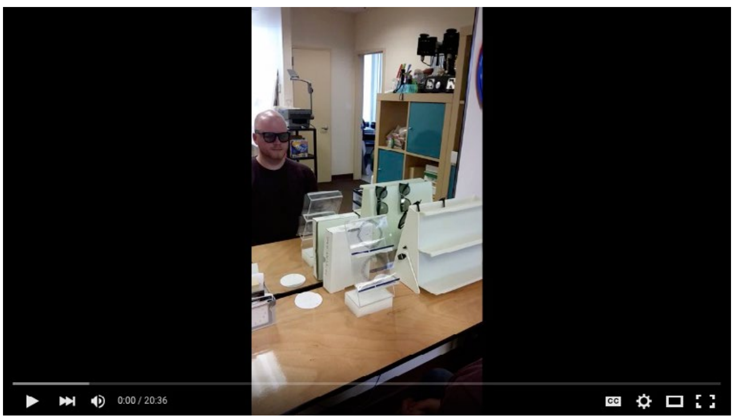
"They are pointing right at the E!"

"That's great. Now can you transfer that to the Gem on the top slide, without the E?"

Another pause, and then, "YES! And it's larger! And farther back! And the arrows are pointing at each other!"

The brain has it.

When working with patients whose binocularity is compromised, remember that the brain is visual. Even without sight, we can function in a 3-dimensional world, and understand visual-spatial relationships. The challenge for these patients is that they have not learned to transfer their motor concepts of space to pair with their visual input. By *showing patients what to look for,* we help them build a bridge between the spatial world that they feel and the spatial world that they see.



In the supplementary video,[2] at 4:49, note the difficulty the patient has in approximating his hands for the purpose of cupping the presented object. This highlights the difficulty he has in visually assessing real objects, let alone the vectogram.

Supplemental Video[2]

This tactile-visual integration technique is introduced to a young man ("TM") who struggled with simultaneous perception in the absence of fusion and stereopsis. He had reported a lack of control over his vision. Furthermore, he observed that when he viewed anything through his left eye, he "felt stupid," like he could not make sense of information coming through the OS. He reported that his vision had always been a hindrance to being able to learn and study in college, despite being very bright. However, he felt he could not put into words exactly what was wrong with his vision for any of the (many) eye doctors he had seen. He had worn a multitude of prescriptions with subtle differences in astigmatic compensation, but "none of the doctors got the prescription quite right." Ultimately, he elected to have refractive surgery… which did not resolve his complaints either.

Diagnostically, he exhibited extreme binocular instability, effectively an "orthotropia": two eyes aiming in the same visual direction… without fusion.

The table below presents a timeline of events in the supplementary video,[2] along with relevant commentary and interpretation. The guidance provided by the doctor/therapist models encouragement, whole-body support, and facilitation of a change in visualization and visual information processing.

Video Timeline[2] and Commentary, Tactile-Visual Integration with Gem Vectogram and "Magic Loops."

Time	Activity	*Commentary*
0:00	Initially attending to lower vectogram, BO target at 2.	*Bottom arrow is seen OS, Top arrow is seen OD.*
0:33	"I'm looking at the middle of the E."	*Patient using central attention, highly focal.*
0:42	"If my focus changes at all, the bottom arrow wants to go to the right."	*Attributes the perception to the vectogram rather than take ownership of his role in the activity. Target image even is personified to have its own volition.*
0:56	Two E's: the circle splits	*Has lost fusion following central attention.*

Time	Activity	*Commentary*
1:17	Bottom system moves right, top arrow stable.	*OD: stable central fixation, OS: drifts to exo posture.* *Patient is reporting simultaneous perception, not fusion.*
1:20	Doctor provides directions to attend to periphery *rather than E*, along with relaxation guidance.	
1:55	Patient clarifies whether the job is to attend to periphery *while keeping the E solid.*	*Very difficult for him to let go of central grasp.*
2:17	Patient disengages, pushes away from task.	*Ready to quit; does not have a history of visual success, and does not yet believe he has the power to overcome his challenges.*
2:25	"As soon as I relax, the E starts going all over the place."	*Attributes the perception to the vectogram: He takes a positive action and the vectogram takes an antagonistic response.*
2:30	Reassure patient, experience is "okay"	
2:39	*Reduced BO demand from 2 to 1.*	
2:54	Guide to relax shoulders.	*Complementary support of the body to relax facilitates peripheral awareness. Anxiety and excess sympathetic nervous tone, on the contrary, may create an over-centered, tunnel-vision effect.*
2:58	"Okay, there: It looks like there is a white circle, and the edges do look circular."	*The "white circle" likely indicates the negative space between the "E" and the inner diameter of the Gem itself. As of yet, he may not have consciously appreciated a large enough volume of space to include the Gem.*
3:15	The E *WAS* staying single "until I started talking."	*First association of his own actions as having an impact on his perception.* *Even though his talking disrupted his perception, this is a positive step, because he acknowledged the disruption as being within his control.*
3:39	Arrows solid, aimed at E, upward-pointing arrow is a little to the left.	*Still in exo posture relative to the Base-out target: Eyes may be directed at the plane of the vectogram/holder (as opposed to generally assuming an exo-posture bias).*
3:57	Giving Gem-shaped object ("Magic Loops") to hold.	*Observe the rigidity of his hands, not ready to receive/feel object.*
4:49	Guide to hold object with separation between index/middle fingers.	*Note the difficulty in approximating shape of REAL object as he places his hands around it: Hands are not automatically assuming shape/size/ dimension of the object.*
5:37	Guiding to feel the object while looking at the vectogram.	*"Eyes don't tell people what they see..."*
5:50	Guiding to see the separation of the two faces of the Gem, as supported by the *feel* of the separation between index/middle fingers, created by the two faces of the object.	*"People tell eyes what to look for."* *Visual imagery induced by the tactile perception is being used to support and enhance the stereoscopic visual perception. The two experiences become integrated, facilitating "solid-seeing," stereopsis.*
6:20	Gazing intently while holding Gem: "Getting kind of hung up on the E"	*Not yet ready to take in periphery.*

Time	Activity	*Commentary*
6:30	Redirecting attention to perimeter, not center.	
6:35	Guiding to relax/breathe	
7:00	More action of his hands, tentatively exploring the object when asked to "feel the shape."	*Not an intrinsically-initiated exploration: He is not sure what to look for.*
7:22	Pushes away again: "I don't know, sorry."	*Giving up a second time.*
7:30	Reassure patient, experience is "okay." Persisting, directing to re-engage, but hold it gently, "like an egg."	*Rigidity of his hands: He is more inclined to "touch" than to "feel."* *<u>May be a similar challenge in patients with Sensory Integration Disorder.</u>*
7:50	Emphasizing volume of space between fingers.	*Awareness of separation of fingers will trigger the spatial map of the hands in the brain.*
8:00	May first perceive as a tangle rather than as a separated, hollow object.	*If over-centered, it is difficult to perceive the surfaces, which require visual processing and integration over an <u>area</u>. When the tendency is <u>not</u> to see the forest for the trees, the attention will be drawn to each "tree," each wire.*
8:30	Building visualization of the shape with verbal support: Largest diameter is between two sides, leading to 2 inner diameters.	*Redirecting vantage to know what to look for and feel for.* *Supporting visual closure and integration of the tactile and visual images with visualization.*
8:54	"Okay, something just shifted, now it looks like a 3D image."	*Engagement changed! Note the shift in posture!*
9:30	Introduce upper, Base-in vectogram.	
9:50	"Upper one is RECESSED, no E." *Do the arrows align?* "It's difficult."	
10:10	Observes the alignment of arrows is less stable, but…	*No central lock to support stabilization of the fixation disparity targets.*
10:25	"wiring of upper one is equally sharp."	*Perceives the base-in, peripheral target without the visual confusion experienced initially on the base out target, even if localizing inaccurately.*
10:40	"Getting to point where eyes are shifting around and it is just staying" (lower one).	*Solid-seeing! = Stereopsis!*
11:05	Guiding to: *Hold the whole shape in alignment.*	
11:27	Guiding to use peripheral awareness prior to refixating between the two objects. "See the top one as recessed in periphery before looking at it."	*This guidance supports the expansion of the functional visual field. Essentially, this takes the non-fixated target out of the "blind spot" by first identifying each one in succession, and then becoming aware of their persistence. Knowing that the two images are present is an interim step to seeing both images simultaneously. Utilization of non-central retina is necessary for retinal disparity and hence for appreciation of stereopsis.*
11:40	Aim at top one, notice bottom one: *Where is it?*	*Asking the question, "Where is it?" encourages spatial thinking and consideration.*
12:00	Bottom one is "further forward… closer to me."	*Relative spatial dimension has now expanded to include both vectograms. Initially, he had difficulty seeing beyond the central E of the Base out target.*
12:25	"appear the same size."	*Not yet appreciating SILO.*

Time	Activity	*Commentary*
12:33	Guide: Start practicing making shift between the two of them. Notice peripheral target, assess where it is, then look at it.	
14:00	Assign relative spatial language before making vergence shift.	*Top-down thinking about relative distance helps to integrate ocular proprioception with image localization.*
14:30	"I am feeling a shift" (in eye posture).	*Elevated awareness of eye position changes, will support his developing a sense of control over his eyes, rather than feeling they are beyond his control.*
14:40	Confirms, they are consistently localizing in the same place.	*Has gained visual stability.*
14:50	"The closer (bottom) one seems like it got a little smaller now."	*Repeated, accurate localization is evoking SILO.*
15:20	Indicates that arrows point at the E on the bottom one, but are "still off" on the top one.	*Localization is accurate on bottom target. Explains why base-out, bottom image has become smaller, but base-in top image has not yet begun to appear larger.*
15:33	Guide: Imagine top one is a little farther away and aim through it.	*Again, top-down guided visualization helps to redirect eyes over a larger volume of space.*
15:55	Observes that arrows remain unstable on the top.	
16:10	Direct eyes farther back, imagine the Gem is a little farther back.	
16:20	"Okay, there we go… I got it for a second, and then it kept sliding."	*Interim stage of ownership: Now taking responsibility for obtaining alignment. However, disruption of alignment is attributed to the target rather than to self.*
16:30	Reinforcing: The arrows are "a little unstable because you are not sure where to look."	
16:35	Explained how to use the relative position of the arrows as biofeedback for eye posture.	
16:50	If you are looking slightly in front, top arrow is to the right: confirmation, release.	*In this case, he has eso-posture. He biases to view in the plane of the vectogram holder, rather than orient to the image.*
17:42	"I keep lining it up, and then IT drifts…."	*Still taking responsibility for obtaining alignment and attributing disruption of alignment to the target rather than to self.*
17:57	Suggest it is okay to let go of the prop.	*Now that patient "knows" the shape he is looking for, he no longer needs to hold the Gem object to help him learn the solid shape of the vectogram.*
18:00	Next, guide further alignment for base-in target with the support of a pointer.	*Holding a pointer in space helps the patient to access information about absolute distance:* *The extension of the arm provides feedback on distance from the body.* *The pointer, being a fine target, can be employed to show physiological diplopia over a tight range, reinforcing when the eyes are aimed at the plane of the pointer.*

Time	Activity	Commentary
18:15	Guide to use pointer to trace the outline of the Gem: outermost outline, in space.	*Guide to hold pointer parallel to the plane of the vectogram(s), for localization feedback.*
19:00	Trying to localize BI target. Found out that the plane of the vectogram slides was in his way.	
19:40	After tracing the BI target, asked patient: "What's happening with the arrows?" "I hadn't even noticed: but now they are kind of lined up!"	*Smiling, finding success.*
19:55	Now, they're *staying* lined up…! OK, interesting!"	*Note that body posture has become more relaxed, at ease.*
20:00	"Okay, yeah, so: when I was doing that [tracing it], the arrows didn't move."	*Has now gained clarity on what he experienced, and now the speech and description come much more freely.*
20:15	Prompted to let go of the supportive props: "Do you know where to look now, without the pointer?"	
20:20	"When I guide my eyes along the outer edges, the arrows are… they stay."	*Language does not yet suggest full ownership over the visual perception: Still externalizes what the target does, but clearly observes this in tandem with his own actions.*
20:30	Congratulations: You now have depth perception!	*Patient releases and laughs.*

REFERENCES

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2. Video: Tactile Visual Integration and Stereopsis. Available at: https://youtu.be/hJwXMPbSRuA.

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