The Mad Librarian Strikes Again

SVEA GOLD

Written for the 30th anniversary of AAHD

Using the headrighting reflex to check for warning
symptoms that something is wrong with the child's
"gaze control" and how to proceed from there.

I was working with a l6 year old juvenile delinquent who was a total disaster. He was hopelessly depressed, moved like a beaten mule, and he never, ever looked at anyone.

And of course, when I tested him - among other symptoms - he had no headrighting reflex. He worked with our neurodevelopmental program – that was the condition on which he was released from jail, but he did so with a great show of boredom.

Much to my surprise, he improved so rapidly that – just to encourage him – I retested him after one month instead of the usual two months interval.
Again to my surprise, he now had acquired a beautiful headrighting reflex. I knew this could be done, but was amazed at the speed of this accomplishment. I told him what an amazing feat that was, but he was totally unimpressed. In spite of this lack of enthusiasm, two weeks later, I asked him: "I can see the change in you – but can you feel it?"
"Yes," he said, "I have more balance."
I said:" How can you tell?"
"On my bicycle."
'Good," I said " And you can breathe better!"
"Yes, and I can look at you now!"

That was my first introduction to the miracle of "Gaze Control" –before I even knew there was such a word.

What miracles can I relate at the 30th AAHD conference that you have not already witnessed in your own experience with helping children? What can I teach you that you don't already know and that actually I might have learned from you at earlier conferences?

As you know, 50 years ago, Carl Delacato already said: "Do the whole thing or nothing at all!" That is what I did with my delinquent. I looked at the whole child – not at the symptoms – and I did the whole program.

And you know what? Today it sounds just as crazy as when Delacato first said to do that. So, today, to show that there is method to this madness, I'd like to share with you a paper that was actually written already 20 years ago. A. Pellionisz, a well-known neuroscientist, wrote an article on "Gaze Control" and that might persuade skeptics that we clinicians actually know what we are doing.

In this field of child development we all learn from each other. Sally Goddard and Peter Blythe of the Institute of Neuro-Physiological Psychology were the ones to introduce me to a technique of testing for a headrighting reflex. Before that I used to look for unusual rigidity around the head and shoulders to alert me to look further for neurological problems. Testing for headrighting reflexes, however, is far more accurate in evaluating how a child functions.

Then, one day, Sally also steered me to a book by J. Allan Hobson who talks about something called “Gaze control”. Testing for a headrighting reflex allows us immediate insight into problems with this complex function – and I will get to that later.
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Gaze control is the magic that happens when a baseball player runs across the field, chasing a ball that is swooping above him in a beautiful arc and then actually catching it. He is always changing his body position in relationship to the ground and to the ball, and yet that ball stays in constant focus in his field of vision.

Gaze control is what lets you see the image on the television set right side up, when you get up from the couch to answer the phone. Even though you are slightly bent over in the process of crossing the room, you can still see the actors on the screen as standing up, and not at an angle.

Many, many of the children we see, - especially children on the autism spectrum - have problems with their gaze. For them seeing is as if they were looking through binoculars on a moving car. We have known it – now we have a name for such a problem.
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In the book, “The Dreaming Brain.” J. Allan Hobson says: The term oculomotor defines itself: eye movement is commanded by brainstem neurons that send their axons directly to the eye muscles. The latter’s highly complex activity which we call gaze, is coordinated via interactions between three paired nuclei, the oculomotor nucleus (or third cranial nerve) which commands primarily vertical eye movements; the trochlear nucleus (or fourth cranial nerve) which commands primarily oblique movements, and the abducens nucleus (or sixth cranial nerve) which commands primarily lateral movements.
The vestibular system of the brain stem is specifically concerned with the complexities of head and eye control. Ask anyone with dizziness or vertigo about the important functions of this system. Vestibular neurons receive information about head position from the inner ear and relay that information to the oculomotor neurons. When the connections between the vestibular and the oculomotor systems are cut, as may occur in multiple sclerosis, paralysis of gaze will result.”

A brilliant Indian autistic Tito Mukhopadhyaya explained it himself: “I can look at you, or I can hear you. I can’t do both!” This is the condition of a newborn baby – the baby stares at sound. It will take more neural development until he can listen and look at you at the same time.
Hobson goes on: “Head and eye position are related in turn, to the spinal control of posture by the reticular formation. Without the constant and precise operation of these three systems, we could neither walk and see nor sit still and read. None of the three functions described is exclusive to any one neuronal group, all three systems being in some way concerned with all three functions. Together with the cerebellum the integrated activity of these brainstem systems is responsible for giving sighted animals complex control of their acts.”

That is a simple explanation, of why as clinicians we have to restore brainstem functions in our children.

And now I am going to play a dirty trick on you and ask you – when you get home - to get on Google and look up: Pellionisz and Gaze Control. If you have the courage to do that, when you download that article, it will send you screaming to your old math books and curse yourself for having slept through trigonometry classes. A.Pellionisz attempts to explain the connections of the various areas in the brain that control “gaze” by expressing the impact of each system in mathematical terms.

He does so, by drawing diagrams of vectors and tensors and eigenvectors. He shows measurement with cosines, contravarients, overcomplete systems and other terms that Einstein would understand, but have my brain spinning. We have a hard enough time explaining to parents why our neurodevelopmental programs work, but just trying to figure out the mathematical vocabulary with which Pellionisz explains what we clinicians basically already know, would easily require a semester of advanced mathematics.

What is a vector? What is a tensor, and what is an eigenvector? And most of all, what does it mean to our children?

A vector is a different concept from the math you first learned in school: namely that 8 and 2 make 10. That is a sum. Nothing in the brain ever works that simply.

A vector is the symbol used by mathematicians and physicists for what happens when two forces interact. The arc that the baseball follows across the sky can be expressed as a vector. The arc results from the interaction between two forces: the power with which the ball is tossed, which would keep it going straight into the atmosphere, and the pull of gravity that would make the ball fall straight down.

A tensor is the mathematical symbol for the interaction when two or more vectors are involved. You can see this kind of interaction when you watch a sailboat being moored skillfully by an experienced captain. He is controlling the power of the wind by changing the angle of the sails; he makes allowance for currents of the water by using the angle of the rudder as counter force; he calculates the inertia of the forward movement of the boat, and in balancing all these different components he guides the boat to settle gently against the pier.
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What is an eigenvector? The eigenvector seems to be the mathematical locus of all the points at which all the forces interact to keep the boat in balance.

And Pellionisz tries to figure out what the forces are that if kept in balance will allow the eye to take the image that hits the retina and then control the eye muscles to react in such a way that the child can keep that image in focus and allow the rest of the body to keep him steady.

Complicated, isn’t it?

What is important to us is not so much that we understand the mathematics of the situation, but that Pellionisz goes beyond the simplistic images that have been used to illustrate the brain and instead tries explaining the importance of the interactions of all the different systems. This is a rare contribution, because even today neurologists split the children’s problems into separate areas. They call it “co morbidity” and make a list of whatever the symptoms are instead of looking at the condition as a whole. That is what Pellionisz tries to do. That is what Delacato means when he says do the whole thing or nothing.

The forces – the vectors Pellionisz talks about in explaining visual functions - depict the connections to and from three main systems: the vestibular, the visual and the proprioceptive. Each system has a vector system of its own. Just think of it: The eyes take a sensory input - light that strikes the retina that actually turns an electric impulse into a chemical - and forwarding the impulse to various parts of the brain that then turns them into a motor expression. Motor expression can mean commanding the muscles that move the eyes and even controlling the muscles that keep the body upright.

The vestibular system takes a sensory input - gravity exerted on the fluid inside the semicircular canals. The movement of the fluid then passes tiny particles along the hairs inside the canals. The way the hairs bend sends information via the cortex as to both position and speed of movement of the head in relation to movement of the body. In turn this information is used to put in motion another set of complicated interactions: stimulating one set of muscles, inhibiting others so that the child can balance and won’t fall down.

You can experience how this works by twirling yourself around until you get dizzy. Then when you stop, you will find that though you are standing still – you may have to hold on to something not to fall down. Though you are standing still, the room is turning around. The fluid in your ears is still moving, and that tells your eyes what they see – it is not the eyes that are in control at this point.

There is an example of a tensor system right there – interaction of several vectors.

How muscles react is also included into Pellionisz’s calculations: Input to the motor cortex includes the proprioceptive which measures the outlines of the body, and the kinesthetic, which measures the movement of the muscles. Each again, takes sensory input: the pressure of the chair against your bottom - the pressure of the weight of a bowl against your fingers to tell the muscles of your arm how much effort it will take to lift it. – these are all vector functions. Now, since each of these systems has to work with the others, that makes it mathematically speaking a tensor system: more than one vector creating an impact.

The Eigenvectors are the symbols that include the conditions necessary for each set of systems - all the combined inputs - that make the functioning of the body possible.

Pellionisz measures the functions of a normal brain. As clinicians we see children only when something is not working for them. So to get back to the image of the sailboat: If any of the forces that allow a sailboat to be controlled by the captain -the wind, the waves, the wheel that controls the rudder become unpredictable, the boat capsizes – falls over or crashes into the pier.

How does that relate to our children? If a child is blind, he may keep himself from falling over by rocking back and forth. He can’t use his eyes to know that when the walls are up and down and the ceiling is at a 90degree angle he is sitting up straight. He uses gravity to tell him at what point he has to rock back so that he does not fall down.

I was working with a forty-year-old autistic woman, who had essentially been blind since childhood.

Her eyes flickered all the time, and when she was standing she was constantly rocking back and forth. By the third week she reported that when she went to church that day, the telephone poles had stood still. I did not understand what she was saying until I realized that her eyes had lost their nystagmus and the poles were not flicking back and forth as her eyes moved.

Another week went by and I watched her talk to someone and suddenly realized that she had been completely still for over ten minutes. She no longer relied on gravity so that she would not fall over. Her eyes were functioning like those of everyone one else.

There was a blind little boy in the public schools. He was only about five years old and already used a cane to feel his way to where he was going. But the moment we took him to an area unknown to him, he started humming. He was using his own sound to echolocate – to get a sense of his surroundings.

You all know of cases like that. These people were using an eigenvector – the point of balance of the different systems at their command - to be able .to function.

Now what is important is not that you learn to understand Vellionisz's paper's mathematical vocabulary, but that you look at the areas in the brain that as a highly respected neurologist he is considering in his calculations.

Neurologists - at least most of the ones with whom I tried to make contact - refuse to talk to us ordinary mortals who deal with real - and unpredictable - children. But we have to make use of their knowledge to be able to explain why what we do is effective.

Even though in this particular study Pellionisz is looking only at gaze control, he challenges his colleagues to stop looking at the brain in just the area that is covered by the funding of their research grant.

He is constantly warning against over simplification, because each system has further subsystems. The vestibular-collicular reflex measures changes in position to the cerebellum. The retino-ocular reflex measures movement and sends the information to the muscles. Some of these controls stimulate, others inhibit. It is all exceedingly complicated and would take a semester to cover.

And most of all, - just as we do - he is also talking about the nuclei in the brainstem, where all the senses interact. He mentions the functions of the cerebellum which not only makes automatic reactions possible but which, as we know, also controls the closing and opening of the iris and the muscles that allow the lens to lengthen or shorten to make it possible for the eye to focus either near or far.

If there is a problem in any of the connections between these systems it will show up immediately when we test for a headrighting reflex. In a good headrighting reflex, the head tries to maintain a steady vertical position to the target. If this does not happen, there is an immediate detriment to the child. With any change in position, the eyes are forced to make the adjustment that ideally the head should make. This puts the child under strain. Not only do the eyes have to do much extra work, but if the target is up close the background always shifts with every move, and if the person looks at a far away target the foreground moves. This always makes the child just a little dizzy. Chances are then that child stops looking at the distance altogether, the optometrist slaps glasses on him – and of course that does not give the child a headrighting reflex.

If testing the headrighting reflex shows any kind of abnormality, this simply gives us a chance to see that there is a problem in one or more of the connections that Pellionisz says are needed for gaze control.

And what happens if the child has no gaze control? He may not be able to read, because the eyes do not move across the line in a smooth fashion. He may not be able to do math, because he may lose focus when making a diagonal move. This means that when he is expected to move his eyes diagonally such as in doing division or square roots, he may lose his place. It is not that he does not understand the concept, but that it's his eyes that are betraying him and jumbling the numbers. Lack of gaze control could interfere with saccadic eye movements from left to right, and so his numbers switch or letters switch on him He thinks he is stupid and his teachers yell at him - but nobody is checking out his vision.

If he has no gaze control, he will get carsick. He can't catch a ball and the other kids make fun of him. The impact has a hundred forms. In the case of the autistic child, his world is never the same twice. When the label is Aspergers, the child can't stand the unpredictability of people faces moving in front of him and so he won't look at them at all – and he can't learn to read their expressions.

Children with huge problems generally find help. The ones with subtle ones, who use one system of the brain to make up for problems in another, are the ones who fall through the cracks. They overcompensate so we don't know what is going on when they have behavior problems or fail academically.

That is where the "Quick Functional Screening" that I use comes in. You can find it on our fernridgepress.com website. I apologize to everyone whose techniques I may have stolen - but that is what I used with my delinquent kids. It gave me the information I needed to find what was wrong and then to check for progress later.

If there is one quick indicator that a child lacks gaze control, however, it is the test for the headrighting reflex. And since I suggest doing the whole program in every case, if you find a problem there, it could easily be enough reason to start such a regime.

We test for four adjustments: forward and back, then side-to-side. This is done once with eyes open and once with eyes closed. If the problem happens with eyes open, that is a clue that there is something wrong in the connection between the input from the eyes and the body. If it happens during the eyes closed test, the problem lies in the vestibular system. If there is a good headrighting reflex, but on return to the midline the head does not straighten itself, we have a problem in the cerebellum. There are enormous variations in the symptoms we see there – but each problem: provides the same clue: We have to go back and do something to get those interconnections going.

It's very simple. We do not try to force a good headrighting reflex, we go way back in prenatal movement to make sure the olivary complexes in the brainstem get the proper input they should have received in utero. After that we try to establish connections in the order in which they should have happened during normal – even prenatal - development.

Doing the whole thing is a shortcut to treating individual symptoms. These are only the results of the fact that something down there is not working. When whatever that “something down there" has been fixed, a proper head-righting reflex will appear of its own.

This still does not fully justify what I have been telling all my parents: Don’t try to fix symptoms. Look at the whole child and then do the whole program!

There is one other aspect that we need to explain as to why we go way back into prenatal movements to make all the connections that will be needed for the child to succeed. Pellionisz does not go into that aspect, but it would be one of the vectors in his tensor system: He deals with the normal brain. To explain how we help our children, we also need to know research on the biochemistry of the brain body function.

Some twenty years ago, Jean Pierre Changeux took fertilized eggs and by injecting curare he paralyzed the muscles of the chick embryos so that they could not make the usual reflexive movements that a baby chick makes inside the egg. When the paralyzed chicks hatched, their brains were abnormal!

Nerve growth factors have been studied for almost 80 years. There are now about 100 different such factors recorded. As a matter of fact, scientists have recently been able to restore walking function in rats whose spinal cord had been severed. They managed this by injecting nerve growth factors near the spinal cord. When the nerve growth factor they used made the axons grow new dendrites, but these did not connect, they found that they had to inject a second, a different growth factor, and that did the trick – the spinal cord reconnected sufficiently to allow 30% of movement to be restored.

In the normal development of the human being, each time a muscle moves certain chemicals are created that send the messages to a specific part of the brain where the development of the brain will then occur. These are called Netrins – a Hindu word for “Guide”. There are many different kinds with beautiful names like Semaphorin, Connectin, and Repulsin. I don’t know if they classify as nerve growth factor, but knowing about them explains why it is necessary that in order to re-map the brain, we have to repeat movements made even in utero. This is especially important because areas in the brainstem, - the olivary complexes, the nuclei and other areas show abnormalities if there has been a problem of any kind on utero. Reflexes in utero create these movements and each guides the needed information to different complexes in the brainstem.

Every reflex has a job of getting information to the brain so that the brain can then fulfill the next developmental function, which in turn will allow the next development to occur. We try the find the lowest reflex working, and stimulate the heck out of it. Then, when we find that the next movement is now smooth, we work that in turn, to fulfill its function.

Each time you move an arm, for instance sensory information is fed into the computer we call the brain, as to how one set of muscles has to be inhibited to allow the other set to work. How much effort has to be exerted just to lift an arm? How much effort to lift an object? How does it feel when the shirt rubs the skin? How do I counterbalance on the other side of my body so that I don’t lose my balance?

Armed with the knowledge that these specific chemicals would make sure that connections would be made to the part of the brain to which it was intended, I designed the program to start with prenatal movements. I figured that there were so many connections in the brain, and we could not possibly know exactly which ones the children lacked, this way we would not miss anything.

At the time I was working with the delinquents I had not even heard the word “gaze control” No one had told me of the Pellionisz article which had already been written in l985. The first thing we noticed, however, was that our children’s walk changed. I’d look out the window and say: “Ah, here’s Eric coming now. No, that’s not Eric. Eric does not walk like that!” But it was Eric! And he no longer rolled along as he used to. Eric walked like a normal human being. Or Emily: “No that’s not Emily – that’s not her walk!” But that was Emily only her eyes were no longer glued to the ground.

In working with kids – and I did this myself every day – we had reached every single area that Pellionisz includes in his mathematical formulas. If we had tried to force Eric or Emily to walk straight, it would have been a waste of time. If we had forced Eloy to look at us, it would have only created more anger.

Delacato would have been proud, Pellionisz might have been surprised that there was an actual clinical use for his vector approach.

When I started this article, I remembered a chart in my files that I had made long after my program with the delinquents ended. The program was not designed as a research study but just out of curiosity I pulled the reports of the intake evaluations. There were 25 kids aged 11 to 18. All of them were brought to me because they had not been able to learn in a regular remediation program. Each one had a slightly different neurological profile, and I’ll be glad to send you a copy. For the purpose of this article I looked only at the headrighting reflex column. Of 25 kids, 24 had specific headrighting abnormalities!

In the years to come, you will be seeing far more cases and saving far more children than I have seen in my experience. You will be using your own methods of working with them, and will see different results. And, as you well know, no two children are alike. Please as you do your testing, check for the headrighting reflex – I am attaching some pages of Sally Goddard’s book “Reflexes, Learning and Behavior” - and do a little research of your own.

I’d be most grateful if you kept in touch and let me know your results. That is the importance of AAHD - that we keep in touch and find new ways to wake up the world as to what can be done to help children.

Christopher Fry has a charming scene in his play “The Lady’s Not For Burning” Young Allizon says to Richard “God moved many lives to show you to me. I think that is the way must have happened. It was complicated, but very kind.”

And whether you believe in intelligent design, Quantum Physics or the Chaos theory - the next time you look at the function of the brain, I hope you agree with me “It is complicated, but very kind.”

Svea Gold, speech for AAHD conference October 2006
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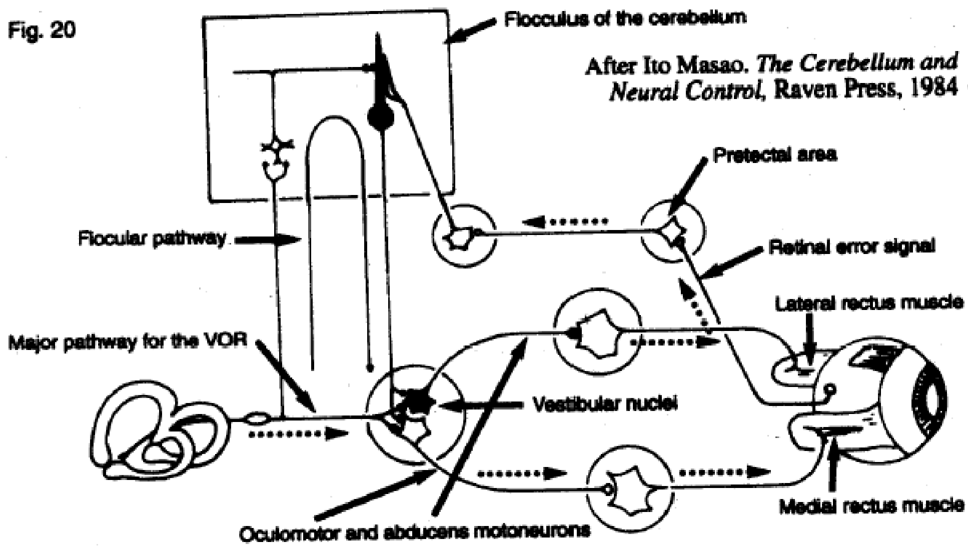
Warning: Though results will be seen very fast, the program needs to be done for several months, depending on the needs of the child. It is described fully in the video " Autism, neurological research and neurodevelopmental therapy." It is meant for any and all unexplained behavior problems on the autism spectrum.

Fig. 20



After Ito Masao. *The Cerebellum and Neural Control*, Raven Press, 1984

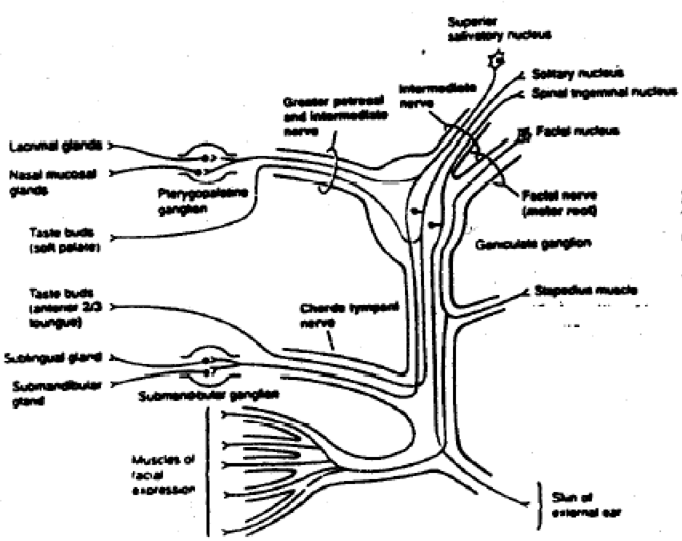


FIGURE 44–6
The peripheral course of the facial nerve illustrates how cranial nerve fiber types can intermingle. The facial nerve and its intermediate branch as well as the petrosal and a branch of the trigeminal nerve (not shown) course together in the periphery.

From : Principles of Neural Science by Eric R. Kandel et al.

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LABYRINTHINE HEAD RIGHTING REFLEX (LHRR)

The labyrinthine head righting reflex is elicited by tilting of the body and/or stimulation of the otolithic organs. The reflex comprises compensatory contraction of the neck muscles to keep the head level.

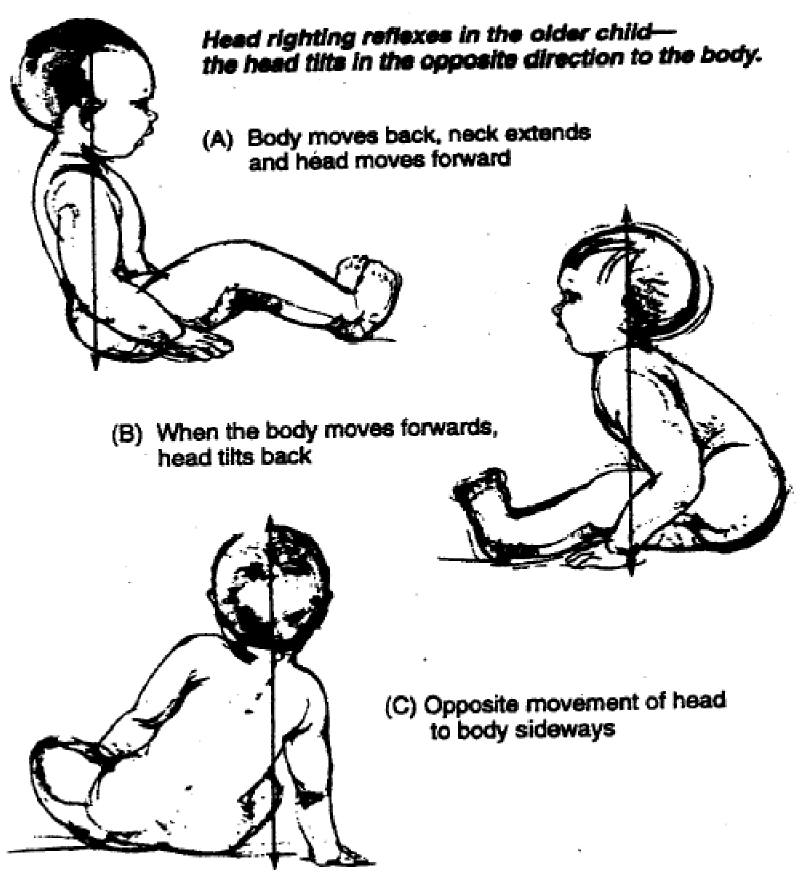
OCULO-HEAD RIGHTING REFLEX (OHRR)

The oculo-head righting reflex is initiated by visual cues and is dependent upon the functioning of the cerebral cortex. It maintains the head in a stable position and *the eyes fixed on visual targets* despite other movements of the body. This is necessary for fixation and sustained visual attention. The oculo-head righting reflex may also be elicited by a combination of visual and vestibular stimulation, stretching of the neck muscles and/or movement of visual images on the retina.

__Otoliths__ — minute crystalline particles suspended in a gelatinous mass into which the hair cells of the utricle and saccule of the inner ear project. They are under the influence of gravity and exert traction on the cilia of the hair cells during movements of the head and the body.

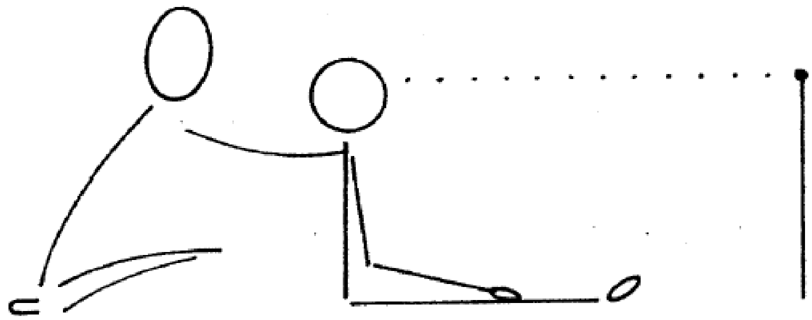
In normal development, the visual abilities to fixate and to follow are enhanced as stability of head posture is achieved. If oculo-head righting reflexes are underdeveloped, visual fixation and visual pursuit can be impaired. This can then affect reading ability, comprehension and spelling.

Head righting reflexes in the older child—the head tilts in the opposite direction to the body.



14 OCULO-HEADRIGHTING REFLEX

Emergence: 2-3 months neonatal
Not inhibited.



Test Position
Subject seated on floor, legs straight in front, arms resting on thighs.

Test Procedure
1. Subject fixes eyes on an object at eye level.
2. Tester sits behind subject and slowly tilts the subject to the left in 3 stages, pausing for 2 or 3 seconds at each stage. Pauses are made at 15°, 30° and 45°. *Note the position of the subject's head at each degree of tilt.*
3. Return the subject to the upright sitting position, again in the 3 stages.
4. Repeat procedure to the right, return to the midline and then repeat the procedure backwards and forwards, ensuring that the subject keeps the eyes fixed on the object at eye level.

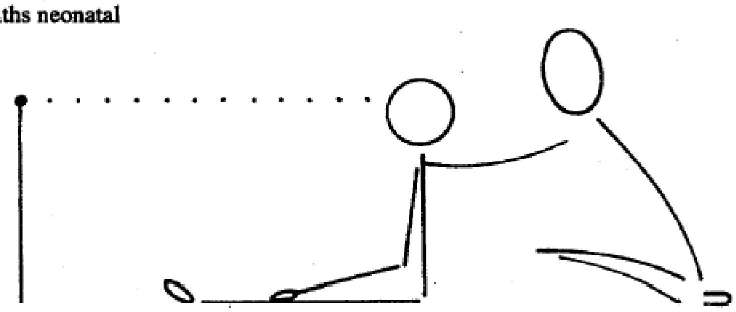
Observations
Head should automatically correct itself to the midline (vertical to the ground) as the body position is altered in all four directions. Any flopping of the head or over-compensation in the opposite direction upon return to the midline position suggests an absent or under-developed oculo-headrighting reflex. Also note any extension of the leg on the side to which the subject is tilted — this may be an indication of a retained asymmetric tonic neck reflex (ATNR) in the leg.

Scoring
0. Head corrects to the vertical midline position throughout the test.
1. Head slips slightly from the vertical.
2. Head follows direction of the tilt in line with the body.
3. Head leans below the line of the body.
4. Head drops in direction of the tilt.

Lack of headrighting forwards/backwards could indicate underlying tonic labyrinthine reflex (TLR).

15 LABYRINTHINE HEADRIGHTING REFLEX

Emergence: 2-3 months neonatal
Not inhibited.



Test Position

Same as for oculo-headrighting reflex, but the subject is asked to fixate his eyes on an object at eye level, and then CLOSE his eyes and to imagine looking at the object during the entire testing procedure.

Test Procedure

1. Subject is instructed to fixate the eyes at eye level object, and then close the eyes and visualize the object throughout the entire testing procedure.
2. Follow the same testing procedure as for oculo-headrighting reflex.

Observations

Note position of the head in all four quadrants, but also note where the subject's closed eyes seem to be directed. (Many children can compensate when their eyes are open, but rapidly lose any sense of where they are in space as soon as the eyes are closed.)

Scoring

0. Head corrects to the vertical midline position throughout the testing
1. Head slips slightly from the vertical
2. Head follows direction of the tilt in line with body
3. Head slips below the line of the body
4. Head drops in the direction of the tilt — no righting apparent.

Also note any compensatory turning of the head — this is NOT the same as automatic righting.

Adaptive mechanisms in gaze control
Facts and theories

Eds. Berthoz & Melvill Jones

Chapter 19

Tensorial aspects of the multidimensional approach to the vestibulo-oculomotor reflex and gaze

A. Pellionisz

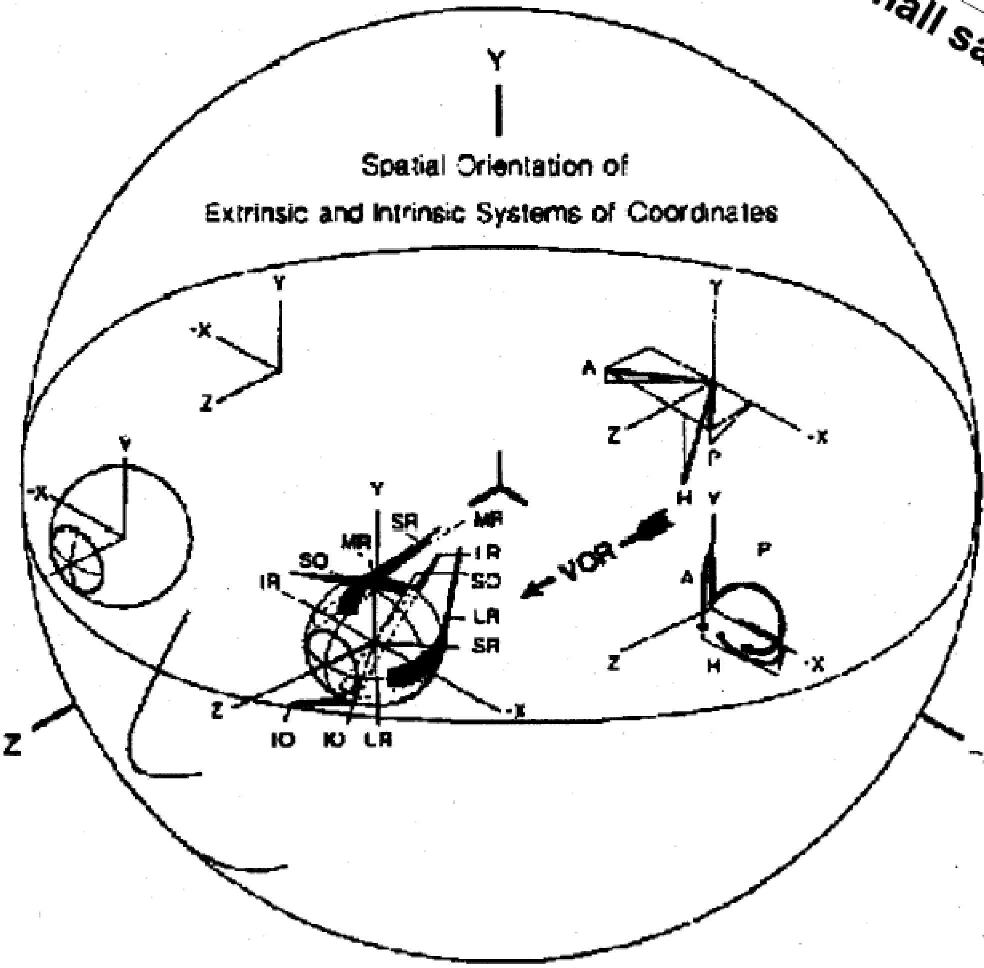


Fig. 1. The two kinds of coordinate systems, used in the external description and in the inner workings of the vestibuloocular reflex (VOR). Extrinsic, yet biologically oriented mirror-symmetric XYZ Cartesian frames (for the lateral sides of the body) are used as medial, dorsal and anterior, respectively. As in biological organisms with lateral symmetry, righthand rule applies to the right side, and left to the left-side. The `standard' position for visual demonstration presents XYZ with equal axes, 120° apart. Semicircular canals represent the HAP intrinsic system of vestibular coordinates, marked as: H, horizontal; A, anterior; and P, posterior. Eye muscles and their corresponding eye-rotational axes are denoted by: LR, lateral rectus; MR, medial rectus; SR, superior rectus; IR, inferior rectus; SO, superior oblique; IO, inferior oblique. These abbreviations apply throughout the paper. The diagram of the eye muscle orientation is drawn with the utilization of the computer model by Ostriker et al. 1985, and therefore both the paired sensory and unpaired motor systems are shown in a quantitatively exact manner.

A. Pellionisz shares much of his vast research on the Internet.
You can Google him or find the material on Gaze Control directly under Pellionisz: Tensor Model of Gaze Control

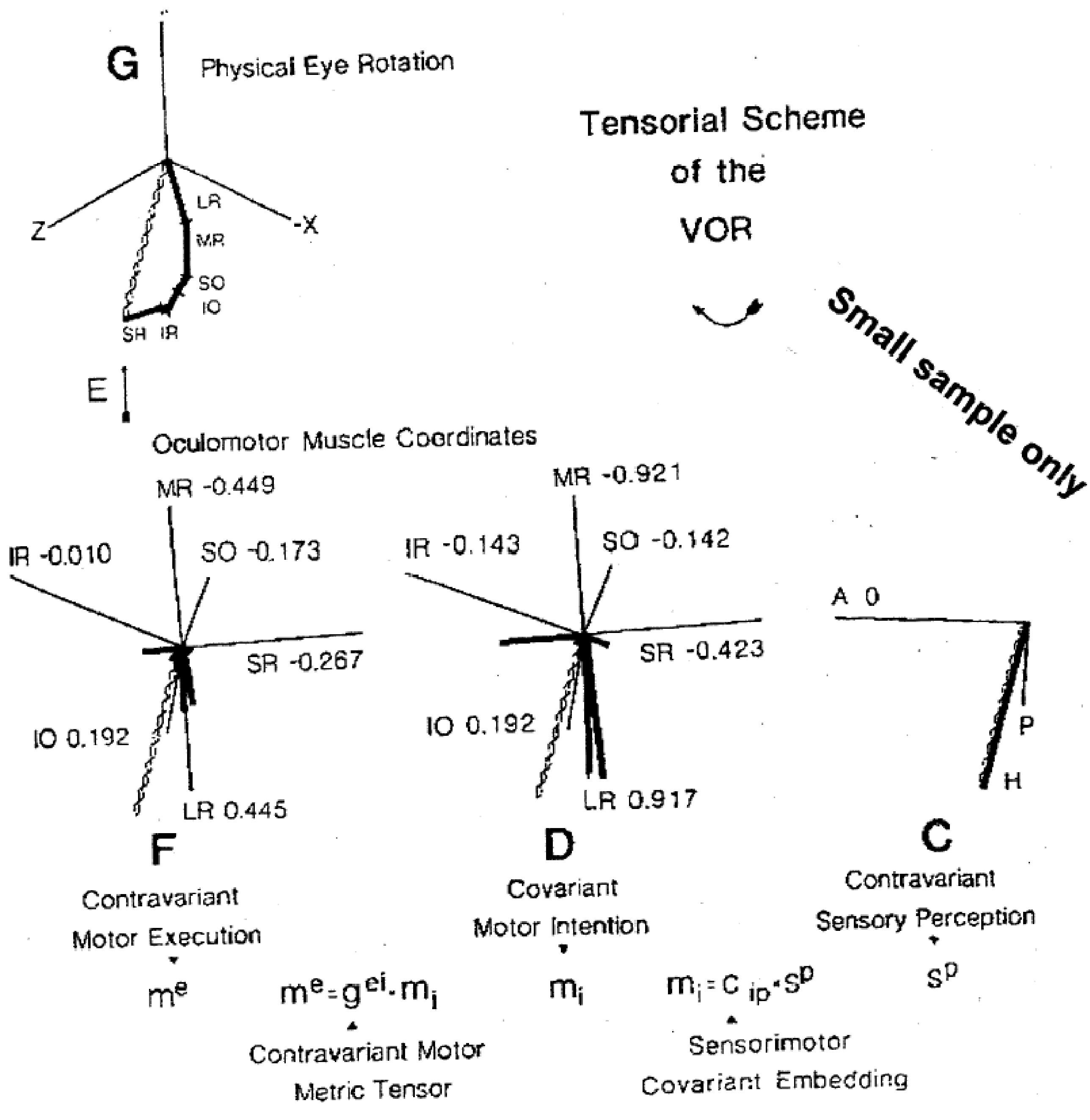


Fig. 3. Tensorial scheme of the VOR. A physical entity, a coordinate-system invariant head rotation is vectorially expressed in extrinsic, orthogonal Cartesian frames (A,G), and in intrinsic non-orthogonal vestibular and extraocular muscle-frames, both covariantly and contravariantly in either (B,C,D,F). A, an arbitrarily selected head rotation, corresponding to maximal excitation of the horizontal canals is expressed in an extrinsic, Cartesian XYZ frame. The extrinsic vestibular matrix V (Fig. 2) transforms these XYZ extrinsic coordinates into HAP intrinsic covariant components, as shown in B (for the vestibular HAP, see Fig. 2V). The BCDF three-step sequence is implemented by neuronal networks peforming a sensory metric g^pr, sensorimotor transfer c sub ip, and motor metric transformations g^ie. The last intrinsic neuronal expression is the contravariant motor execution vector me, which generates a physical rotation by activating the eye muscles. The extrinsic eye-muscle matrix E (Fig. 2) can