clinician's view

Neural Systems Integration:

Improving Performance in Children with Learning Disabilities

by W. Michael Magrun, M.S., OTR/L

"This book should be in the library of all rehabilitation professionals."
– William V. Padula, O.D., FAAO, FNORA

"This is a 'must read' for all therapists who work with infants and children."
– Josephine C. Moore, Ph.D., OTR, FAOTA, DSc. Hon. (2)

"This is a work that is sorely needed in the therapy professions."
– Christine A. Nelson, PhD, OTR, FAOTA, NDT Coordinator Instructor

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Integrating Neural Systems:
Improving Performance in Children with Learning Disabilities

Introduction

The foundation for skilled performance lies in the ability to match and integrate neural systems, particularly the visual, vestibular, and somatosensory systems. Within this triad, the infinite possibilities of movement, posture, and skill acquisition exist. Each system has fundamental characteristics that provide us with knowledge of our external and internal world. These sensorimotor systems allow for the dynamic process of matching information, re-weighting information, and integrating information that is task-specific and provides the foundation for learning through experience. Weighting and re-weighting refers to how the sensorimotor systems are intra-organized and how functional tasks, movement, and learning are a complex interplay between systems, not only in anticipation of the functional task, but within and during the activation and process of the task. The sensorimotor systems have interchanging responsibilities and varying levels of influence during task-specific performance.

Functional performance is both a top-down and bottom-up process. Function is driven by cognitive desire, orientation to a task, reactions to outside forces within the task and, of course, is learned through practice. Function is goal-specific and is therefore often described within a top-down model.

Function requires a foundation of musculoskeletal alignment, postural organization, and mechanical factors, to allow the initiation and the maintenance of a task-specific movement. Without this “dynamic foundation,” there can only be splinter skill training. Practice on a misaligned, posturally disorganized base, will result in compensatory function and a learning process that is confined to the child’s dysfunctional range of performance, thus, “splinter skill” learning. The sensorimotor systems responsible for organizing the underlying foundation for skill acquisition are sometimes described within a bottom-up model.

Obviously, we must always consider this interchange of functional initiation both from a volitional, or proactive learning process, as well as from a non-volitional, reactive supporting process. Both processes are simultaneously engaged in all performance and learning experiences. So it is fundamental to our clinical thinking to understand not only the success or difficulty of a functional process, but even more so the underlying efficiencies or inefficiencies that contribute to, and are the ultimate reasons for, success or failure.

This text will discuss each major sensorimotor system, its functional importance and influence on other systems. The concept of neural systems integration will be presented as a dynamic weighting and re-weighting process between systems that provides the foundation for skilled performance and learning. The concept of the visual-vestibular-cervical triad as a basis for neural system organization and integration will assist in the understanding of how neural systems interact. A problem in one system can result in compensatory inefficiencies. Each system leads, and is lead by the other systems, through

Comparator Systems & Internal Maps

This diverse processing allows for information to be compared (comparator systems) with efferent copies (corollary systems) and ultimately helps to develop an anticipatory nervous system prepared to initiate a process already knowing the outcome. Each experience stimulates a modification of the whole system so that there is a constant re-weighting of sensory organization (16). For instance, the amount of force and strength used to pick up a heavy object as opposed to a lighter object is anticipated and stability/mobility factors are initiated before lifting the object. Similarly, the anticipatory control and motor sequences initiated walking down a set of stairs knowing and anticipating each step prior to taking the step. It is why we are “surprised” when we expect an object to be heavy that turns out to be light as we initiate picking it up with too much force and must make a feed-back adjustment, and why we are “surprised” when we expect that there is one more step when there is not, as we abruptly “feel” the floor, instead of an additional step. We anticipate the force, amplitude, strength and movement ranges necessary to carry out a known task. We initiate feed-forward “proactive” sensorimotor sequencing. Feedback allows us to confirm success of the anticipatory initiation. When we are “surprised” the feedback is abrupt and alerting and we make reactive recovery and then reset a new anticipatory sequence.

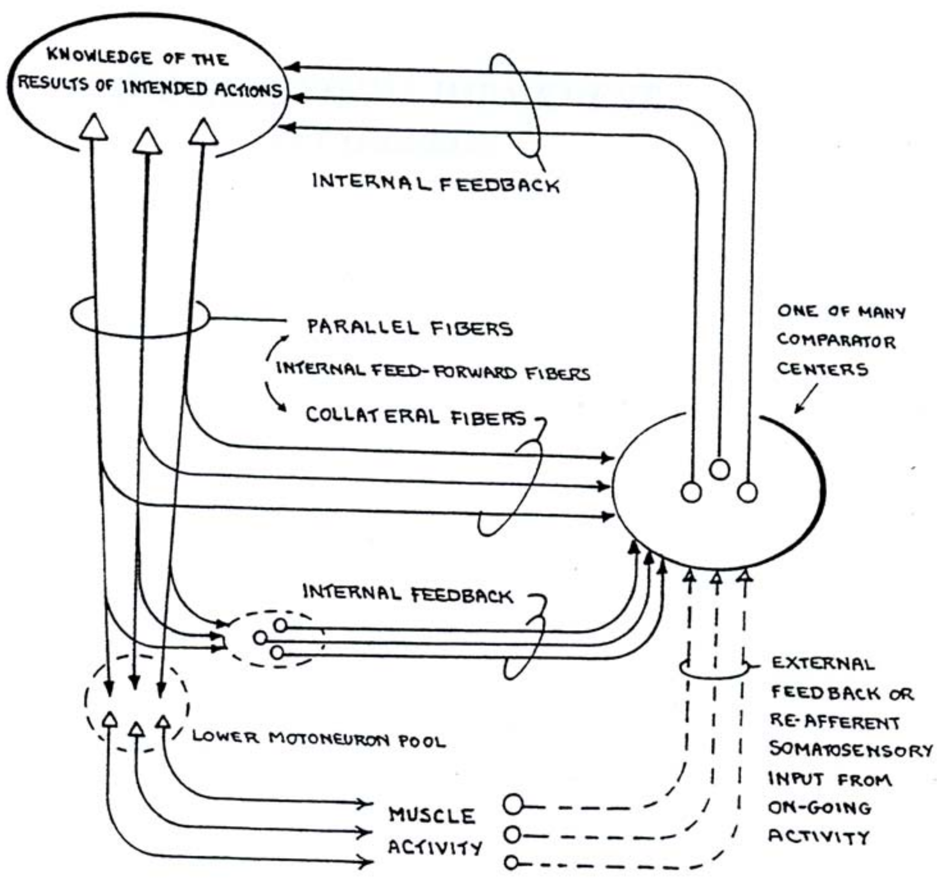
Internal maps, both sensory and motor, exist for comparing the external environment with internal perceptions and performance. This process results in matching of information that confirms the action or performance or identifies mismatching that requires adaptation and correction for a successful outcome. Comparator systems are both hard-wired and soft wired. Hard-wired comparator systems are those that are more basic such as reactive righting and equilibrium responses, reflexive reactions and basic automatic reactions necessary as a foundation for developing a repertoire of more sophisticated movement patterns. Hard-wired systems rely primarily on feedback. Soft-wired comparator systems are those that are built up through experience and environmental exposure to opportunity and experimentation. These comparator systems develop through repetition and the ability to interact spontaneously with the environment in a vast variety of ways and are less dependent on feedback than on feed-forward initiation of known outcomes (corollary discharge) based on its known repertoire of comparator circuits and internal maps. Corollary discharge disperses the intended action to comparator systems that automatically initiate feed-forward action and compare and correct ongoing activity. Figure 4 shows a schematic of the interrelationships between comparator and corollary discharge centers.

Figure 4. Comparator System & Corollary Discharge
Drawing by Josephine C. Moore, Ph.D., OTR, DSc. Hon (2)
Schematic of corollary discharge. Reprinted with permission.

FOR A GIVEN MOTOR COMMAND, THESE SIGNALS WILL BE SENT TO SEVERAL COMPARATOR CENTERS, AS WELL AS TO THE LMNs (LOWER MOTONEURONS) WHICH CARRY OUT THE COMMANDS.

3. THE COMPARATOR CENTERS COMPARE THE INTENDED RESULTS OF AN ACTIVITY WITH THE ON-GOING ACTIVITY AND MAKE INTERNAL CORRECTIONS IMMEDIATELY IF THE ACTIONS ARE NOT CONGRUENT WITH THE INTENTION.

B. COLLATERAL FIBERS AND PARALLEL FIBERS, ALONG WITH INTERNAL LOOPS ARE INVOLVED IN COROLLARY DISCHARGE. THUS THE CODED MESSAGES SIGNALLING THE INTENTION CAN BE DISPERSED TO SEVERAL CENTERS SIMULTANEOUSLY WHERE THEY ARE COMPARED WITH THE INTENTION, OR THE ON-GOING MOVEMENT, IF NECESSARY.



The Importance of the Neck

Neck control in children with learning disabilities has been documented repeatedly as being less than optimal and is evidenced by residual head lag and elevated shoulders as a compensatory stability substitution. In addition, difficulties in assuming and maintaining supine flexion and prone extension responses have been associated with vestibular dysfunction in sensory integration theory (10,11).

As previously stated, the neck is critical in the organization of sensory processing for motor performance. According to systems theory (1) at about 2 months, coordinated neck musculature action for posture is present. This is followed by the mapping of the visual system to the neck musculature, followed by the mapping of the somatosensory system to the neck, followed by mapping of the vestibular system to the neck. This priority mapping is significant for understanding the influence and importance of each sensory system to postural control and each other.

Once postural neck control is established in the first two months, vision becomes the driving force for the development of movement and posture up to around 7 years of age when the somatosensory system becomes more primary for postural control. This shift in sensory system "weighting" allows the visual system to become more involved with spatio-temporal awareness, feed-forward processes, and experiential learning.

An interesting study by Kennedy (19) supports the notion of the importance of the neck in adequate vestibular function. She placed normal 3, 5 and 6 year-olds on a rotating disk used in the postrotary nystagmus test developed by Ayres (12), with and without a stabilizing head device. The postrotary nystagmus responses of the 5 and 6 year-olds correlated with and without the device. The responses of the 3-year-old children did not. Their responses were much less organized without the device. This suggests that the postural control of the neck musculature, and its relation to trunk control at that age, is not sufficient to maintain the correct 30 degree alignment of the semicircular canals for a normal vestibular response to rotation. The important conclusion here to understand is that many children with learning disabilities have low-normal postural tone and reported poor neck co-contraction. The question arises as to whether vestibular dysfunction as reported in the sensory integration literature, is being confused with a lack of rostral neck control and somatosensory and visual matching to allow for vestibular responses to be organized. Most children labeled as having vestibular dysfunction in sensory integration theory are labeled based on clinical behavioral interpretations. These clinical behaviors, however, have other alternative interpretations that will be discussed.

Figure 5 shows residual head lag in a 5-year-old child inverted on a ball being pulled up to sitting. Several clinical assumptions may be made. There could be a possible vestibular dysfunction resulting in a lack of initiation of head lift against gravity. There could be a lack of neck strength and co-contraction resulting in the inability for the head to right itself in relation to the trunk. Since the stimulus for head lifting here is pulling on the arms, a somatosensory and joint traction stimulus (reactive response to external input), it is likely that the neck is not able to stabilize well to allow vestibular-visual information to assist and maintain the head position. And if we look carefully at the child's eyes we see he is not visually orienting to the plane of action. Eyes that are in a consistent upward alignment bias the body toward extensor tone. Eyes that are consistently in a downward alignment bias the body toward flexor tone. In addition, the head-back and neck-extended position is the most challenging for vestibular organization (20).

Figure 5

Five year old child being pulled to sitting from supine on a ball. Residual head lag evident. Neck does not activate to stabilize for head raising, therefore eyes do not orient toward the midline.

Figure 6a, 6b, 6c shows an 8-year-old child attempting to assume supine flexion after instructions and demonstration. Head lag is obvious in his attempt. There are several different ways to explain this clinical observation. There could be a vestibular dysfunction that results in poor activation of head lifting. There could be poor neck control resulting in the inability to elongate and flex the head/neck thereby diminishing the opportunity for the vestibular-visual systems to activate with the neck musculature to lift the head as the initial response to supine flexion. There could be a lack of visual alignment of the eyes to orient the head and signal the musculature and vestibular system to activate. Since the initiation was based on cognitive instructions and not ongoing movement, the response is proactive and therefore more likely to be a result of poor neck strength and/or visual regard interfering with necessary alignment to initiate the required plane of movement.

Figure 6a

Figure 6b

Figure 6c

Eight-year-old child attempting to assume supine flexion on command after demonstration.

Asking a child to assume supine flexion (proactive soft-wired response) is activated through anticipatory feed-forward mechanisms of the somatosensory system. Figures 6a-6b shows an inefficient response while Figure 6d shows an efficient somatosensory initiation with confirmatory visual and vestibular support.

Figure 6d

Ten-year-old child maintaining controlled supine flexion after initiating from a supine lying position.

When evaluating a postural response, it is important to be aware of the position and initiating stimulus. Slowly tilting a child backward will result in a graded flexor response to the change in the center of gravity (Fig. 7a). Quickly tilting a child backwards will

The Importance of the Somatosensory System

In addition to the importance of neck proprioception, somatosensory input from the rest of the body has also gained more attention. The somatosensory system is increasingly being suggested as a primary influence on vestibular function and balance maintenance. Cruthchfield and Barnes (29) state: “the vestibular system is not as critical to maintaining certain conditions of balance as was once believed, that is, balance is not provided by the vestibular system alone.”

Studies on muscle states, tension, golgi tendon organs and muscle spindles, indicate that proprioceptive information shapes reflex responses and is the root of postural maintenance. Further, proprioception was seen as the most important factor in postural alignment. (30). Alignment is so critical to balance and the maintenance of posture that structural integrity of the musculoskeletal system is the first thing that should be evaluated in order to determine its effect on postural control (29).

The base of support, namely the feet and ankles, plays a critical role in balance. Studies have identified the importance of the biomechanical constraints of the ankle and the importance of an ankle synergy in balance. Small perturbations do not challenge the center of mass and are easily handled by reactions at the ankle as long as there is a firm support surface and the outside force is not too intense (29). Ankle strategies do not necessarily require vestibular input to maintain balance. This is important when we evaluate children with postural disorganization in terms of the structure and activity of the feet and ankles. Poor structure will result in a progressive compensation through the legs and pelvis and trunk and contribute to a chain of inefficiencies in balance, movement and posture.

Hip synergies are activated once the center of mass goes beyond the control of a stable base of support. Hip synergies assist in activating vestibular responses. Horak et al. (31) indicates that the cutaneous and joint somatosensory information from the feet and ankles play an important role in assuring postural control and monitoring appropriate biomechanical constraints and once hip strategies are activated vestibular information along with somatosensory information contribute to the selection of postural movement strategies.

Shumway-Cook and Woollacott (1) describe neuroscience studies of postural control under various tilt conditions. In standing, when the tilt was small and the surface firm the primary balance reaction was initiated at the ankles (ankle strategy). In standing when the tilt was larger and the surface was a narrow balance beam, the primary reaction was initiated at the hips (hip strategy). When sitting on a surface without the feet on the floor, the primary response was initiated with the trunk (trunk strategy). These investigations were conducted without interfering with vision or vestibular conditions. In other words, different challenges require different postural responses. These responses require a flexible postural system in order to make the necessary adaptations to challenges in balance and equilibrium.

In the three above studies, the musculoskeletal system reacted differently to different environmental demands, suggesting that there is a selective process by which the somatosensory system reacts to balance challenges. These experiments involve hierarchical reactive conditions where balance is compromised from unexpected external forces. The ability to adapt to these postural changes is largely dependent on the integrity of postural tone, alignment, musculoskeletal strength, etc.

In addition, Mittelstadt (32, 33, 34) has recently reported the discovery of graviceptors in the trunk. These receptors are important in the perception of body posture and according to Mittelstadt, these somatic graviceptors equal or surpass the contribution of the otoliths and further contribute to the control of the posture of the eyes, neck and limbs. In order for the eyes and otoliths to know the spatial orientation of the body to vertical, the relationship of the position of the eyes to head to trunk must be known which is deduced through efferent copies measured by proprioception. Thus, proprioception mediates the perception of position that allows the sense organs in the head to orient to vertical.

If we think about how establishing trunk stability and mobility in children with both neuromotor and postural disorganization positively affect the quality and adaptability of movement, the importance of truncal proprioception to establishing alignment and therefore sensory matching becomes more evident.

In other experiments it was found that somatosensory loss increased vestibular sensitivity (31). The results suggested that under conditions of neuropathy or if the surface was unstable, the vestibular system was more sensitive to the control of posture. Interestingly however, this study reflects two different conditions, peripheral neuropathy or loss of proprioceptive information, and an unstable surface, or proprioceptive disruption. Obviously proprioceptive disruption results in a reactive state and therefore a more reflexive process. Vestibular sensitivity is thus logically increased to initiate trunk and head and neck reactions to maintain balance. Conversely vestibular responses are negated or dampened in self-generated (proactive) movement to allow adaptability and dynamic motor control and efferent feed-forward processes without disruption by constant vestibular weighting for balance reactions (35). Dynamic movement is context dependent and the interaction of sensory systems is completely different than in reflexive activity. In neuropathy, however, this increase in vestibular sensitivity is compensatory, not reactive. There is a loss of proprioceptive information due to the disease state requiring the vestibular system to compensate. Compensation is an entirely different process than integration.

Applying this notion to children with learning disabilities who are considered vestibularly over-reactive or over-sensitive, there may be a link or mismatch between poor organization of proprioception from the base of support, diminished somatic input, and vestibular reaction, rather than a vestibular problem. Diminished reception of somatic proprioception due to low tone, intolerance of weight bearing on a body side due to a visual midline or somatosensory midline shift, would likely result in an increase in vestibular sensitivity contributing to a hypersensitive vestibular state and therefore a matching of sensory systems under inefficient conditions; in other words, a mismatch of normal.

How do these concepts relate to children with movement and posture disorganization associated with learning disabilities? Because the V-V-C Triad may not be well organized and integrated, these children may not have developed efficient more adaptive sophisticated soft-wired comparator systems or internal mapping or signal coding. Thus they tend to function more stereotypical with less spontaneous adaptive motor planning (Figs. 19a-19d). Contrast Figures 19a-19d with the smooth, spontaneous adaptive motor behavior of a normal 5 year old shown in Figures 20a-20f.

Figure 19a

Figure 19b

Figure 19a shows a nine year old child playing with a toy. Notice the sitting posture, with rounded back and posterior pelvic tilt and wide base of support. Figure 19b shows an adaptation that maintains the wide base of support and posterior pelvic tilt and rounded back.

Figure 19c

Figure 19d

Figures 19c and 19d show the lack of variability of movement as the activity progresses.

Figure 19c shows the next adaptation consistent with a lack of variety. The legs stay in nearly the same position at the hips. Posterior pelvic tilt and flexion of the trunk maintain as the child moves over his wide base. Figure 19d shows the child’s response to the toy moving away and pursuing it with straight plane movement and consistent posterior pelvic tilt. This response would not be expected in a child with adaptable postural control as it is inefficient for reaching forward to pursue a toy. The child's wide base of support never changes thus not allowing a more adaptive response using lateral displacement of the center of gravity or trunk rotation.

Figure 20a

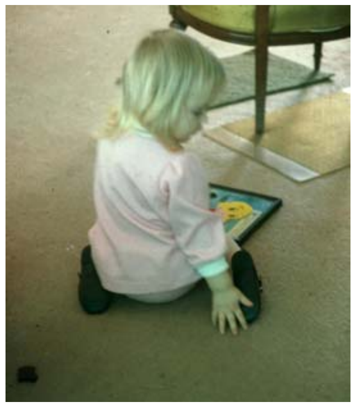


Figure 20b

Figure 20c

Figure 20cd

Figure 20de

Figure 20f

Figures 20a-20f shows the variety of adaptation at play of a normal 5 year old. Contrast the variety of postural responses to the figures above of the 9 year old. Note how this young girl naturally places her foot in contact with the surface for a stable pivot point. The legs adapt as the center of gravity is shifted and the arm is used for support as needed.

Stereotypical motor behavior is less versatile than dynamic motor adaptation. Reactive feedback responses are more inefficient for activating a smooth repertoire of movement responses that adjust to changing demands and show the lack of variety referred to as "limited" motor adaptations. Figures 21a-21h shows another example of what some call "poverty of movement" (4). The movement activity is limited in variety and adaptability.

Figure 21a

Figure 21b

The center of gravity is unable to shift over the base of support.

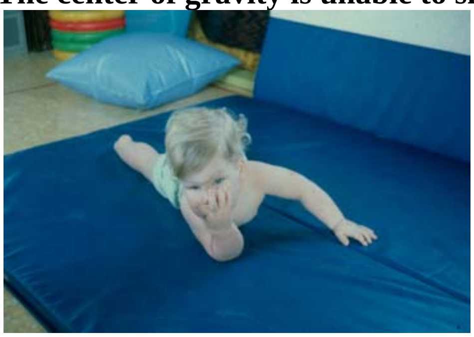


Figure 21c

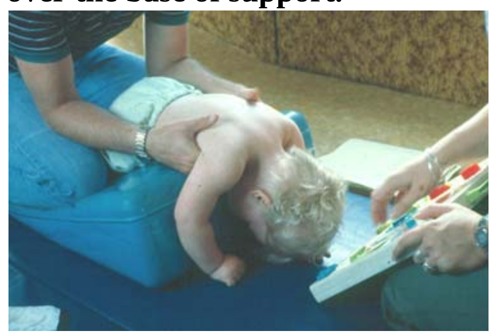


Figure 21d

Simple lateral weight shift over the elbow but the long extensors are insufficient to lift the head.

Figure 21e

Figure 21f

Lack of adaptability in the trunk results in pushing the head against the surface to accomplish a change in alignment.

Consider the following example: The young adult in Figures 32a & b suffered a closed head injury. He was discharged from the hospital without any Neuro-Optometric assessment of his functional vision. This individual, as can be seen in Figure 32a, is unable to walk without losing balance, or leaning up against the wall for support. In fact he was "testing" with his foot for the surface before each step.

Figure 32a

Figure 32b

Figure 32a shows the independent walking of a young adult after closed head injury. There is obvious lack of balance and inability to shift weight to his left side.
Figure 32b shows the immediate results on motor control and balance after the introduction of prism lenses without any other intervention.

Dr. Padula then placed a pair of base right prisms on this individual, due to what Dr. Padula assessed as a right visual midline shift. Base right prisms have the affect of shifting the perception of space left. Figure 32b shows the immediate results with no other intervention.

This remarkable example should impress the reader with the importance of the ambient visual process in motor control. The somatosensory and vestibular systems had no problem relating to the new shift in ambient perception of space, clarifying that the problem was not a physical musculoskeletal-motor problem or a vestibular problem, but a visual distortion problem. This response can also be related to the confirmation by Josephine C. Moore and others that the CNS recognizes and is drawn to constellations of input characterized as "normal" (29). Due to the visual distortions and the dominance of the visual system in all movement, this individual's CNS related "normal" to be a shift of body orientation to the right. Applying vestibular therapy and/or physical handling to bring the posture back to midline, without changing the individual's perception of space would have been ineffective, if not frightening and potentially dangerous. This example should give therapists pause before applying treatment techniques without carefully evaluating the potential interaction of the visual-vestibular-cervical (somatic) systems.

Prism lenses are prescribed by optometrists to affect the way that space is perceived, and to affect how the body reacts to that change in perception. Prisms are 3-sided transparent pyramids that have a base and an apex.

The Importance of the Vestibular System

The vestibular system plays an important role in balance and postural control. The vestibular system, like the visual system and the somatosensory system, is a proprioceptive system. Integrating these three forms of proprioception is essential for efficient movement and posture.

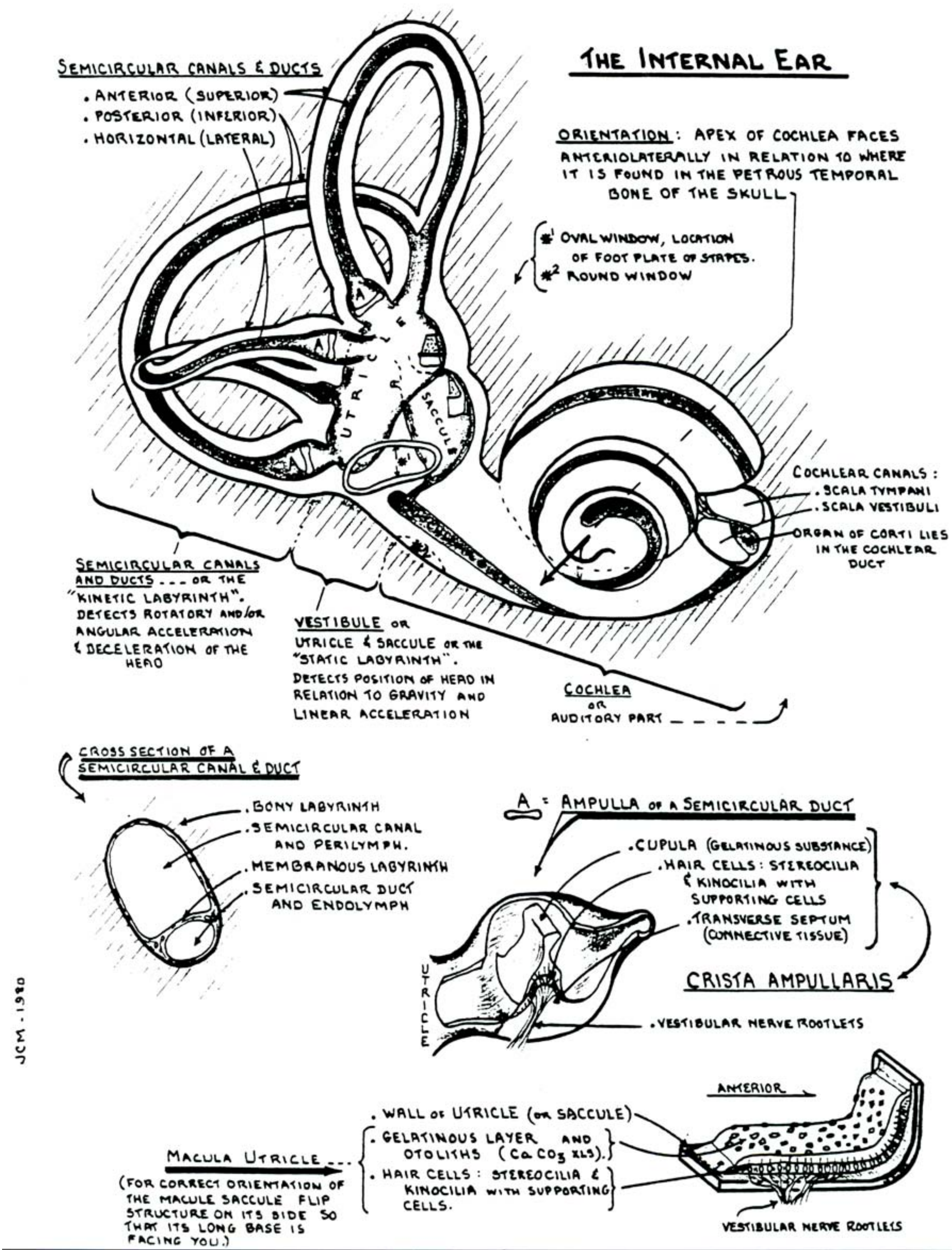
Functionally the vestibular system consists of parallel structures, the semi-circular canals and the utricle and saccula. The three semi-circular canals register rotational acceleration. Structurally each canal is located in a different plane such that rotational forces can be measured and integrated in all planes of movement. Within the semicircular canals is a receptor organ that reacts to rotational forces.

Within the utricle and saccula are the otoliths which respond to the force of gravity and linear acceleration. The otolithic organ in the saccula functions to keep vertical orientation to gravity. It measures linear accelerations of up and down and back and forth. The otolithic organ in the utricle responds to lateral or horizontal forces and registers linear accelerations side to side.

These five individual motion sensors work dynamically in all planes of movement to maintain balance and equilibrium, monitor motion of the head and neck, and stabilize the eyes relative to the environment. Normal movement involves all aspects of these five motion sensors. We rotate as we bend diagonally forward or back. We accelerate forward and turn our head laterally. We stop, start, turn, and constantly tilt and sway laterally, forward, and back. Every movement we make combines some aspects of the five vestibular proprioceptive sensors. And in order for this information to be relevant and efficiently used it must be matched with what is happening with the eyes, visual perception of space, the neck, and the body proprioceptors, both upper and lower body. So movement is an extremely complicated process and a harmonious dance between our proprioceptive senses. Each proprioceptive system is dependent on the other. Imbalances in any system will cause compensation by the others. In some cases compensatory responses maintain efficiency, particularly through the visual and somatosensory systems. However, many times compensations are inefficient and practice of inefficiency strengths the imbalances.

Understanding these interrelationships is important to observational assessment and treatment strategies. They must be appreciated in total. Much of our testing attempts to isolate specific aspects of our sensory systems, For example the vestibular-ocular-reflex (VOR) has historically received a large amount of interest as a way to determine vestibular dysfunction. And to some extent there has been an assumption of the dominant influence of the vestibular system to ocular control. Interestingly, the VOR is reflexive, while the visual system is responsive. The VOR is important for maintaining fixed gaze on an object. This is critical when chasing an object like a baseball, or running after an animal or a person. Fixed gaze is important to maintain contact with an object of interest and regardless of the bouncing of the head or effects of terrain on the movement, the eyes maintain stabilization. However, we do not always, nor constantly, move with a

Figure 39. The Structure of the Vestibular System
Drawing by Josephine C. Moore, Ph.D., OTR, FAOTA, DSc. Hon. (2)
The Structure of the Vestibular System. Reprinted with permission.



fixed gaze. We constantly shift our gaze, perhaps periodically returning to an object of interest but certainly we do not function through life with eyes fixed. Therefore the VOR is only helpful in certain situations. The VOR must be released or inhibited so that we can shift our gaze, scan our world, and attend to other stimuli within a task-oriented context (44). So the visual system can initiate through various pathways, feed-forward processes that regulate the vestibular systems reflexive reactions, while at the same time these reflexive reactions can be instantaneously invoked when needed to maintain gaze, then regulated to release. This dynamic interplay of volitional proactive movement intention, superimposed on underlying reflexive reactive responses, provides movement and postural control, intention, maintenance, recovery, adaptability and functional skill acquisition.

Rotational movement around the body axis involves the horizontal semicircular canals. There are no standard tests that can totally isolate the superior or anterior canals, so rotational tests measure only one function in the absence of actual body movement through space or in consideration of visual and somatosensory influences. So when we test for vestibular function using rotation we are attempting to evaluate the horizontal semicircular canals.

Otolithic organs are important to the organization of body sway and therefore weight shifts, which are a part of all movement. When we move laterally, the otoliths in the utrical provide inertial mass through the movement of otolithic-gel. This provides for a reactive righting response to maintain verticality. The otolithic organs in the saccula respond to gravitational forces in body sway forward and back and up and down. So when we are tilted forward or back, for example, we respond with head righting to maintain vertical. The two otolithic receptors of the utricle and saccula give us all three planes of movement to which we can react.

Again these responses are reflexive but can be volitionally inhibited or dampened in context-dependent tasks. For instance we use forward flexion to get up from a chair, to pick up an object from the floor, to get up from a lying position, etc. In actuality, many if not most movements we make comprise an initial component of forward flexion. We don’t stand up by thrusting backwards, for instance. Therefore in proactive volitional movements we must dampen the utricular otolithic response. Similar to dampening the VOR, it is context-dependent. When we intend to get up from a chair, we set up efferent copies throughout the CNS and anticipatory muscle activation of the trunk, neck and lower limbs precedes the movement. The head goes forward and that “controlled” proactive inertial force is used to increase musculoskeletal reactions to take weight over the feet, stand and then return the head to vertical. This is completely different from having your chair unexpectedly tilted forward. Again there are proactive response initiated behaviors superimposed over reactive, reflexive support. In all movement there is interplay between these factors depending on the level of difficulty of the task.

The otoliths, like the semicircular canals, do not initiate movement but react to it. Volitional proactive movement is initiated through the visual system or through cognitive desire, and sets up potentials for activation of the somatosensory and vestibular systems.

Figure 40a and 40b depict differences in sensory organization between right and left foot balance. Figure 40a shows a more exaggerated (vestibular) reaction of the upper body while holding the legs together for compensatory proprioceptive stability. The right side does not participate in maintaining the body weight for the left foot to lift. This would be an example of a vestibular dominant attempt. Figure 40b shows better alignment and control on the left side but again holding and bracing with the hands and legs for compensatory proprioceptive stability. This would be an example of a proprioceptive dominant attempt.

Figure 40c

Figure 40d

Figure 40c shows relative success at right foot balance with the tendency toward compensatory proprioceptive stability seen in the posturing of the right arm, fisting of the right hand, and elevation of the right shoulder. Figure 40d shows an exaggerated vestibular reaction to the attempt to assume and maintain left foot balance. Again there is no clear weight shift onto the standing leg. Without a clear and controlled weight shift the vestibular system is more activated to attempt reflexive compensations. Contrast these examples with the example of a normal 5 year-old.

Figure 40e

Figure 40f

Figure 40e&f show a normal five year-old easily able to balance on either body side with a clear and controlled weight shift to the standing leg and without a vestibular reaction.

Physical Handling to Change Neuropostural Organization

Direct physical handling treatment, emphasizing normalization of bilateral weight tolerance, to establish more appropriate structural and body alignment, graded weight shifts, and the incorporation of rotational patterns, has shown improvement in posture and one-foot balance without specifically providing vestibular stimulation. Magrun (52), Nelson and Benabib (53) demonstrated improvements in postural organization and one-foot balance in children within 5-10 hours of treatment (figures 39a-39d). These postural changes were accompanied by reports from parents and teachers of improved behavior, school performance, and self-image.

Figure 41a Before

Figure 41b After 5 Hours

Figure 41a shows the standing alignment of a 9-year-old prior to physical handling treatment. Figure 41a shows the change in standing alignment after 5 hours of treatment (consecutive daily 1 hr. treatment sessions). Notice the elevation and scapular abduction in Figure 41a and the relative improvement of shoulder and scapular alignment in Figure 41b. The head and neck are also slightly extended before treatment and there is better head alignment and neck elongation after treatment.

Figure 41c Before

Figure 41d After 5 Hours

Figure 41c shows right foot balance attempt before physical handling treatment. Figure 41d shows the improvement after 5 hours of treatment. With more organized weight shift

The Concept of Multiple Midlines

Rotational components of movement, particularly with diagonal planes of movement are the "integrators" for graded controlled postural adaptations. These learned ("soft-wired") components of postural movement integrate earlier more limited "hard-wired" reactions such as those that were described in the past as "primitive postural reactions." They organize and utilize flexion and extension in terms of the degree and range of rotation.

Neuronal group selection theory (61) suggests that primary repertoires of movement and spontaneous movement patterns, such as described by Prechtl (62) are present at birth and are modified, secondarily and tertiarily into more variable and integrated movement patterns through developmental sensorimotor experiences. This concept correlates with the neuroanatomical concept of "pruning and tuning." (Pruning and tuning is a phrase first coined by Josephine C. Moore, OTR, PH.D., FAOTA, DSc. Hon (2) as a description of how the nervous system matures and develops). Important in these more dynamic modified patterns are rotational components of movement.

Rotational components require dissociation of body segments and limb movements and therefore provide the variability and adaptation of responses that are required to generalize sensorimotor skill and direct it for learning. Rotational - diagonal movements require an integration of visual, vestibular, and somatic information. Rotational movements assist in integrating and making more efficient the matching of these systems.

Mary Quinton (63) eloquently described the development of these rotational and diagonal processes through her construct of "multiple midlines." Rather than think only of one midline of the body that runs vertically from head to feet, Quinton suggested that there were other organizational planes, or "midlines" of the body. She identified vertical, horizontal, lateral, and diagonal midlines that she observed from her experiences in direct handling of infants with developmental challenges, over many years.

This concept is important because it provides an understanding of how dissociation and integration of early primitive patterns takes place and therefore provides the foundation for adaptive postural responses and the ability for unlimited modification of movement and learning.

As Quinton states, *"We think of a midline as a directed line of sensorimotor activity, a hypothetical pattern of activation, that moves along an axis in relation to which movements take place. It is a hypothetical line which lies at the center of a pattern of synergic activation and which later becomes a focus of organized integration. We may think of the midline as a line of energetic or dynamic activity that is the guideline for integrated movement. This new way of thinking about movement organization provides the therapist with a deeper understanding of the progression and integration of postural control as it develops in infancy…. To think of more than one midline for the human body is rather a new idea. We are accustomed to thinking only of the vertical midline that is recognized as the hands of the infant come together over the chest and in front of the eyes. Now we will develop an image of various midlines that play an active role in organizing the postural and movement control of the infant. The realization of this multiple midline organization* (in children with disabilities or disorganization) *occurs through active* *therapeutic handling. By considering and visualizing these hypothetical midlines, we can organize the sequences of developmental movement in a way that permits us to recognize incomplete or inadequate developmental patterns. On the basis of such observations the therapist can assist more effectively and directly, the infant, who has special challenges in development.”*

Quinton suggested that midline development, through various planes of movement, organizes emerging “mobile-stability” of the head, trunk and limbs and is the foundation for function to emerge spontaneously through developmental experience. These midline organizational patterns integrate earlier, more primitive (less adaptive and more stereotypical reactions such as the ATNR, TLR, etc.) patterns, sometimes referred to in past literature as “primitive postural reflexes.”

Vertical and horizontal midlines provide organized symmetry, while lateral and diagonal midlines refine sensorimotor responses that incorporate dissociation of body segments and in this way provide the possibility for adaptive postural control upon established vertical midline stability. Quinton felt that the development of these various midlines activated the “chain of righting reactions” and integrated them into more dynamic movement patterns.

Vertical-horizontal midlines refer to the vertical and horizontal axis of the body. The vertical axis is identified by the vertical arrow, and the horizontal axis is identified by the horizontal arrow (Fig43a).

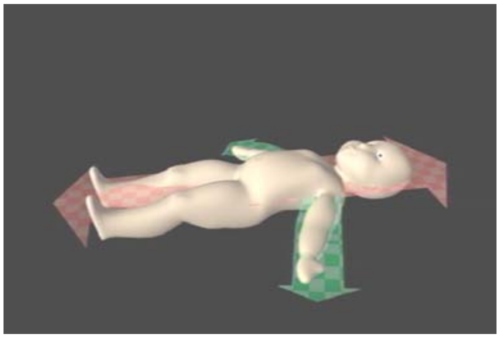


Figure 43a

There can be movement of the horizontal over the vertical as shown in Fig. 43b or movement of the vertical over the horizontal as shown in Fig 43c.

Ribs that are flared and do not coordinate respiratory adaptation with phonation or movement, cause trunk disorganization and impact postural adaptation and movement control (Figs. 47a&b)

Figure 47a

Figure 47b

In general we know that many children with movement and posture disorganization do not choose to spend much time in prone. This impacts the development of neck control, easy head turning, and elongation of the neck. It further results in a lack of antigravity responses in the chest and trunk, limiting lateral trunk movements and contouring of the rib cage. Lack of postural experience in prone negatively influences the organization of midlines and the adaptation of the rib cage for respiratory support of movement and mobility necessary for developing efficient rotational patterns. Lack of experience with sustained head/neck control in prone, normally seen well established by 3 months of age, will limit early matching of the visual-vestibular-cervical triad (see Figs. 15b &16).

Rotational patterns permit grading of our movements, provide skilled control of flexion and extension patterns, and integrate lateral weight shifts in a wide variety of possibilities. Rotational movement is one of the keys to organized motor control and provides the ability for graded use of dissociated movement. Rotational patterns permit the development of a well organized integration of visual-vestibular-cervical relationships. Rotational patterns do not develop their maximum efficiently without well established vertical-horizontal-lateral midline organization and structural and functional development of the rib cage.

Children with learning disabilities, as previously described, show inefficiency in rotational patterns, tend to move in straight planes with a wider base of support, and cannot control lateral weight-shifts well. These factors directly influence bilateral integration, coordination, and the efficient matching of the visual-vestibular-somatic systems, that are needed for efficient learning. Skilled movement requires graded dissociation of movement of limbs to each other as well as to body segments, in both lateral planes of movement, anterior and posterior planes of movement, and combinations of various planes of movement. Rotation through diagonal organization allows for an almost infinite variety of movement combinations.

the visual system persists past this point developmentally, it interferes with dynamic postural adaptation and becomes a visual-dependence pattern. Visual over-reliance will interfere with anticipation and therefore motor planning. The visual system will function more as a feedback system as opposed to a feed-forward system, thereby, inhibiting dynamic sensorimotor anticipation necessary for efficient learning and performance.

This same condition is often observed in children and adults with neurological disorders. Individuals with closed head or brain injuries become subject to their visual distortions, and the somatosensory system is unable to make proper dynamic postural adjustments because the visual system signals a spatial orientation that is incorrect. Without intervening visually, through orthoptics and prism lenses, there can be no rebalancing for efficient sensory matching between visual, vestibular, and somatosensory systems. Re-weighting will not take balance and functional performance will deteriorate.

An over-reliance on somatosensory information leads to a *surface-dependence pattern.* This condition relates to an inability to adjust to changes in surface inputs. When the surface is more challenging, such as on sand, an incline, thick carpet etc., the individual is not able to adequately use ankle or leg proprioception to maintain dynamic postural verticality. This causes balance difficulties which activates reactive processes and inhibit feed-forward anticipatory efficiency. This type of dependence is often related, not only to sensory issues but more likely, to biomechanical and structural issues as has been previously discussed. Regardless of appropriate vestibular or visual function, sensorimotor performance will be limited due a lack of an adaptive and efficient somatosensory system. Intervention that does not address the fundamental underlying biomechanical structure and alignment of the body will not be effective in improving functional performance, regardless of the amount of vestibular stimulation or visual therapy that is performed. Re-weighting of sensory systems, that must be dynamic and interchangeable throughout a functional performance, will not take place if the somatosensory system is limited in its ability to dynamically respond to the base of support.

When inaccurate information from one or more senses is experienced, individuals with *sensory selection* problems are unable to select a sense with accurate information to overcome the faulty sensory information. These individuals are best at maintaining balance and postural control when all sensory information is consistent and accurate. When there is conflict between sensory systems they are unable to maintain efficient postural control. The inability to make sensory selection under varying conditions inhibits the possibility for re-weighting of sensory influences required for efficient sensorimotor function. Under this condition, sensorimotor function is primarily reactive. Since there is a lack of dynamic re-weighting and sensory selection, feed-forward anticipatory proactive sensorimotor function suffers. This condition is observed in patients with CVA, TBI, and developmental disorders. It would seem logical that a primary focus in therapy would be to establish one primary sensory system that can be relied upon for matching of other systems. The primary system most powerful for orientation in space is vision. Establishing good visual orientation can help provide the ability to organize the other systems around the accurate information of the visual system.

Summary

How the neural systems match within a functional context will determine the efficiency or inefficiency of learning. If they are matching reactively, then there is a constant feedback process of dealing with outside influences. It is less adaptive and more reactive, within a feedback dominated context. When they are matching proactively, there is a feed-forward initiation of the adaptability of neural systems that is supported by the underlying reactive processes of the neural systems. The variations in the reactive and proactive nature of neural systems will assist in determining which sensory system may be “locked in” to a compensatory process that inefficiently matches with other systems, causing further inefficiencies. Changing the adaptability of that system leads to “unlocking” of the compensations of the other neural systems. Thus, a more dynamic matching can be guided through reorganizing how these neural systems relate, release, and re-weight.

Sensorimotor control and sensorimotor learning are dependent on appropriate sensory system matching between visual-vestibular-cervical and somatic proprioception. Sensory system responses are both reflexive (reactive to outside forces) and proactive (self-initiated behaviors). These two unique but intricately intertwined processes must be supportive, integrative, and able to shift and re-weight depending on the nature, demand, challenge or threat of an activity. To intervene effectively with children with movement and posture disorganization, it is important to understand this dynamic interplay. Preparation activities to establish musculoskeletal integrity may be necessary. Stimulation activities to arouse or activate systems may be necessary. Facilitating controlled equilibrium and righting reactions may be necessary. All these preparatory procedures, however, should be incorporated into meaningful transitions that allow the sensory systems to match effectively for efficient function. Physical handling that gradually allows spontaneous control by the child would appear superior in strategy than simply child-directed, stimulatory, compensatory practice, or other forms of intervention that do not specifically guide dynamic sensorimotor organization, and can often result in practicing and strengthening dysfunctional processes.