The Vestibular Sense

David Brown continues with his series of articles highlighting some of the less well-known senses

Function

Our other sensory systems provide information about ourselves or about the environment around us, but the Vestibular system is unique in providing a continuous flow of information about the 'fit' between the two, the person and the environment; it tells a person how they are interacting in the environment and it enables the individual to remain oriented in space and in time. This is the sense that tells us about the position of our heads in relation to the pull of gravity, it tells us which way is 'up', and it detects motion. As a consequence of this it monitors and directs muscular activity and body position to maintain secure and functional postures whatever we are doing, working very closely with the touch and proprioceptive senses. It also has very close links with the visual sense, in particular stabilizing the fixation point of the eyes when the head moves which enables us to maintain a stable visual image of the world as we move. Since the Vestibular system only provides information about the position and movement of the head it relies on well-integrated links with the senses of proprioception and vision to facilitate postural adjustments in the rest of the body. If, for any reason, the Vestibular system is not working then these other two senses (vision and proprioception) can, with great conscious effort, be made to compensate to some extent and provide a degree of postural control and security.

Two writers give interesting broader perspectives on this sensory system that really emphasize the great extent of its contribution to all of our functioning:

"In the final analysis, one may have a well-developed sensory map of the external world and a well-developed motor map of movement from one place to another, but if one does not know where they are with respect to that map, they are virtually incapable of using that spatial mapping information. And the Vestibular system appears to be the system that gives information about the individual's location in the overall spatial map" (neurologist S.J. Cool in 1987).

Jean Ayres, an occupational therapist and the creator of Sensory Integration Theory and Therapy, is more concise and states simply that:

"The Vestibular system is the unifying system. All other types of sensation are processed in reference to this basic Vestibular information. The activity in the Vestibular system provides a framework for the other aspects of our experiences."

Most importantly, Ayres declared that the Vestibular sense plays a key role in helping us to develop effective self-regulation of our arousal level, our ability to maintain a calm but alert state. So this is a sensory system that plays an extremely important role in enabling us to do almost everything that we do in our daily lives, and yet very few people know about it. In sensory terms, this is the big one.

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Structure

The Vestibular apparatus shares space in the inner ear with the cochlea, which is part of the auditory system. The Vestibular apparatus is divided into two sets of receptors to monitor the two different kinds of head movement, angular acceleration (which happens when we shake or nod our heads, bend over, or roll over in bed) and linear acceleration (which is what happens when we are in an

elevator moving up or down or in a car moving forwards). Let's look at these two sets of receptors.

The semi circular canals

First the semicircular canals. There are three of these in each inner ear, arranged at right angles to each other so that they meet up in just the same configuration that two walls and the floor meet in the corner of a room. These angles correspond to the three planes in which we move (horizontal, vertical, and on the diagonal), so each of the three semicircular canals is designed to detect motion in a single plane. Their job is to detect angular acceleration of the head and by acting together as two matching sets, one left and one right, they tell our brains exactly what position our head is in at all times, and what direction it is moving. The matching sets of Vestibular apparatus on each side of the head are designed to work together, of course. If infection or damage causes the semicircular canals on one side of the head to send the brain information that disagrees with information sent by the semicircular canals on the other side of the head, then the brain gets confused about what the head is doing and the resulting conflict will lead to feelings of vertigo and nausea.

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The vestibulo-ocular reflex (VOR)

As they monitor all movements of the head, the semicircular canals also organize compensatory movements of the muscles that control eye movements, so that the fixation point of the eyes remains on a stable base rather than moving about the same as the head; specific head movements trigger specific semicircular canals to activate specific pairs of eye muscles in specific ways that enable this. This is a remarkably complicated but quick acting reflex sequence. The amazing thing is that although it stabilizes our visual fixation for us, we can then superimpose voluntary eye movements upon this stable base whenever we wish to. This compensatory reflex, complex and smooth and rapid, yet something that we don't need to think about at all, is called the vestibulo-ocular reflex. You can identify the reflex at work with a simple experiment. If you hold a book very still and try to read part of it as you move your head side to side and up and down and round in circles, it might not be particularly comfortable, but it is perfectly possible to keep your eyes reading and following the lines of print, thanks to your semicircular canals which are being activated by your head movements. But if you keep your head absolutely still and somebody else keeps moving the book around in front of you it is impossible to read along the lines of print since your semicircular canals are not being activated by any head movements, and your voluntary eye movements are totally incapable of keeping pace with the movements of the lines of print in the book. This gives you a small idea of what it must be like to try to use your vision when the semicircular canals are damaged in some way.

The utricles and the saccules

The other set of receptors in the Vestibular system are two sack-like structures called the utricles and the saccules. The utricles lie horizontal when the head is upright and they detect linear motion in the horizontal plane, while the saccules lie vertical in the upright head and they detect movement up and down and forward and back. These two pairs of organs keep us vertically oriented with respect to gravity, and any movement away from upright triggers the head-righting reflex, which leads to correcting postural adjustments. When we think we are standing quite still and vertical we are, in fact, rocking very slightly back and forth or side to side in order to trigger this reflex to help us to maintain correct vertical posture.

The Equilibrium Triad

Postural and gravitational security, and a good sense of equilibrium, both

depend upon the effective development and functioning of three different but interdependent sensory systems (an "Equilibrium Triad"), namely the vision sense, the Vestibular sense, and the combined tactile/proprioceptive senses. For many children with deafblindness, especially children with CHARGE syndrome, all three of these sensory systems are likely to be missing, impaired, or malfunctioning, which largely explains the slow development of large motor skills and mobility, but also makes it remarkable that so many of these children do eventually stand up and walk. The good news is that any input and experience that helps to improve the functioning of any of the sensory systems in this Equilibrium Triad can, therefore, be regarded as making a contribution to the development of good postural control that might result in independent standing and walking – it is not only about the Vestibular sense.

Why does the Vestibular sense go wrong?

- A damaged, or missing, Vestibular system.
- Cerebral palsy and other sorts of brain damage which result in abnormal muscle tone, limited movement abilities, and problems with tactile and proprioceptive perception.
- Certain infections, medications (and alcohol!).
- Over-stimulation (for example, motion sickness), which can result in feelings of nausea and vomiting.
- Blindness, low-vision and visual perception difficulties.
- Lack of use resulting from movement difficulties, from feelings of insecurity and fear, or from a generally low level of motivational drive due to limited stimulation, limited sensory perception, or ill health. Like all sensory systems, if the Vestibular sense is not stimulated, challenged, and used it will not develop effectively.

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The Vestibular sense and deafblindness

When we look at the list above it is possible to imagine that many children with deafblindness will have difficulties with their Vestibular perception, either because of malfunctioning or absence of the Vestibular apparatus (as is common with CHARGE Syndrome, for example), or because of other issues that are on the list. Because the Vestibular apparatus plays a crucial role in organizing sensory perception through all the other sensory channels this problem has a profound effect on all areas of functioning and behavior for the entire life of the child. However, its importance and impact is usually over-looked and under-played, especially once the child is standing and walking independently.

Jean Ayres realized a long time ago that knowledge of Vestibular function was crucially important when considering a child's visual difficulties. In 1981 she wrote that as early as the mid-60s:

"We could see that visual processing problems were central to learning disorders, but we needed to look beyond vision. If you just look at children from a behavioral standpoint and do behavioral type research and modeling, you'll never really discover that a main foundation to visual perception is the Vestibular system, with proprioception and other senses also contributing."

She went on to discover more about the central importance of this sensory system that we all need to study and understand if we are to work successfully with children with deafblindness. Here are some of the important connections:

Vision

So there are strong links between the Vestibular sense and vision, as already explained. Problems with Vestibular perception may affect the ability to maintain a stable visual field, but it may also make it difficult to follow objects smoothly with the eyes as they move, and to differentiate whether it

is the object or oneself that is moving. Some children may appear to 'go blind' if their postural security is too challenged, but they may surprise us by showing some well-developed visual (and other) skills once they are flat on their back or on their side on a stable surface. This apparent paradox shouldn't surprise us because Jean Ayres told us a long time ago that, after air to breathe, postural security is our next most urgent priority; without postural security none of us is going to focus our attention on reading a magazine, or on listening carefully to a radio broadcast, or on carrying out a complex fine motor task like sewing or writing. First we save ourselves from falling, or reorganize our position to get more secure and physically comfortable, and then we do our reading or listening or sewing. As they get older, children may use residual vision to help them to stay upright (think about the Equilibrium Triad), compensating for having a poor Vestibular sense by using the strong visual impressions made by horizontal and, especially, vertical lines in a room (for example corners, the edges of windows, doors, table tops, and wall-mounted pictures). They may have much less equilibrium outdoors where these strong visual markers are largely absent or beyond their range of vision. One result might be a reluctance to go outdoors, for example during recess at school, and another might be an inability to perform certain tasks when they are outdoors that they perform very well indoors. For children who are reading, the use of a typoscope (a letter-box shaped frame) can help by isolating one single line of text at a time. Similarly, the use of large print on a computer might be very helpful to a student, not because their visual acuity is poor but because they need help to isolate the line of text on which they should be visually fixating.

In addition to vision, the Vestibular sense links with many other areas of functioning:

Hearing and understanding sequencing

There are links between the Vestibular sense and the ability to process sound, to perceive and remember auditory sequences, and so to develop spoken language. For children with Vestibular issues this has implications in addition to other hearing difficulties, and a truly collaborative approach that brings together a teacher of the deaf, a speech therapist, and an occupational therapist trained in Sensory Integration Therapy (or any combination of these) should be very helpful. Difficulties processing auditory input contribute to problems with language development, and also to problems with memory and with learning many basic academic skills. We all need to move to some extent in order to listen, but children with Vestibular problems may need to move even more to listen and to understand, so that, when they are standing, telling them to "Stand still and listen" could be counter-productive. Understanding and remembering visual and movement sequences are also likely to be more challenging if the Vestibular sense is significantly impaired.

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Memory

An absent Vestibular sense is likely to have a negative impact on the development of memory, which, with the difficulties with the effective use of vision (especially fine central vision), and with the processing of auditory input, will have a cumulative impact on speech and language development, and on receptive understanding of visual language (for example sign language, finger spelling, written language). Resultant difficulties with expressing themselves, or the constant experience of having their expressive communications misinterpreted, can lead some children to give up, or to resort to explosive behaviors that may be construed as unpredictable, irrational, or emotionally disturbed. Significant problems with the Vestibular sense can also inhibit the

development of effective body language, since postural control, equilibrium, muscle tone and motor coordination will all be impacted.

Attention/ distraction and levels of arousal

If arousal levels are abnormally high or low, and the child has very limited ability to self-regulate because of problems with the Vestibular sense, they may never attain that 'calm but alert' state that is essential for effective learning.

Muscle tone/ postural control and security

Very persistent low muscle tone is often associated with severe Vestibular problems. Low tone is also associated with low vision, breathing difficulties, and generally reduced sensory inputs, hence reduced perceptual awareness. The problem is then compounded by the lack of motivation to move and the resulting lack of "exercise." Protective reactions, standing, cruising, and independent walking usually develop very late. When children do walk, there is often a characteristic gait, some aspects of which may remain evident for many years – the feet spaced widely apart, the knees bent to lower the center of gravity, the body rolling from side to side with each step, the feet sliding along the floor or planted down very firmly on the floor with each step (maybe several times, almost like patting the floor with the foot), and the arms held up like a tightrope walker. Some children walk with repeating swaying circular movements of the upper body and head, as if trying to keep aware of the danger areas at the limits of safe posture by alternating from one 'danger' position to another. On-going monitoring by a physical therapist is important because there is a high risk of the development of neuromuscular scoliosis (curvature of the spine) in childhood and the teenage years.

Bilateral coordination/ orientation and mobility

Bilateral coordination, the ability to use both left and right sides of the body independently and also together, may be significantly affected, with one side so dominant that the other side of the body is ignored. Hand dominance and eye dominance may be very late developing, or one hand and eye might be so dominant that the child is effectively functionally one-eyed and one-handed. Remember also that, when it is working effectively, this is the sense that tells a person how they are interacting in the environment, enabling them to remain oriented in space and in time. Add these challenges to blindness, and to poor body awareness due to limited tactile and proprioceptive feedback, and it seems amazing that many children with deafblindness do manage to learn and remember routes at all.

Breathing/ feeding skills/digestion and nutrition

Because of resultant low tone, poor head control, preferred horizontal postures, and limited movement, these are all likely to be adversely impacted.

Sociability

As can be seen from this list, significant difficulties with the Vestibular sense cause disorientation and confusion in most aspects of daily living, particularly when there are other sensory impairments present also. Unless people involved with the child are prepared to understand these difficulties and adopt a supportive and non-judgmental attitude, then the child is likely to develop a strong distrust and dislike of others. This is especially regrettable when people repeatedly stop the child doing the very things that enable them to function – things like adopting specific postures or using self-regulation strategies that are interpreted negatively as 'self-stimulating behaviors'.

What can we do to help?

- Respect compensatory behaviors as functional, and help the child to make their own choices. Prohibit anything dangerous, of course, but otherwise do not attempt to remove or replace any of these compensatory behaviors until their function has been established.
- Suggest evaluation by an occupational therapist (preferably

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trained in Sensory Integration Therapy) and a physiotherapist, and implement their suggestions. Regular input from therapists is very important for all children with Vestibular dysfunction, but these therapists will need to be informed about the existence of severe balance problems and about the implications of this.

- Pace activities to facilitate optimal functioning and to minimize fatigue and stress. Functioning with little or no Vestibular information is an extremely challenging and tiring business, so breaks and rest periods may need to be frequent and extensive.
- Remember that work that improves the functioning of other sensory channels can help to ameliorate the impact of Vestibular difficulties.
- Younger children, and those with physical disabilities, may need to be lifted and carried, which could be very threatening for them if they have poor Vestibular functioning combined with other sensory impairments. Handle them to minimize stress, for example, by using consistent anticipation cues, using an appropriate speed & direction of movement, and providing adequate physical support for both the head and the limbs during movement as well as for the child's body.
- Always make appropriate physical support available (for example, seating, a table, things to lean against, or you yourself). As these children get older the problems with fatigue, postural control, and sitting or standing unsupported may be less evident but still present. Sometimes the student will benefit from using an adapted chair, with arms and a footrest, possibly also with the seat tilted forwards to encourage more active sitting against gravity. Alternately, some children may benefit from provision of mobile seating such as a suitably sized therapy ball, which can facilitate repetitive rhythmic motion of the lower trunk and legs which helps the brain to know where the body is and that it is all secure and under control (rather like the way we all sway around slightly when we think we are standing quite still). There may still be a great need to support the head by propping it up or by resting it on one or both arms or even down on the desktop itself, in order to read or write. Also remember that extended periods standing still and entirely unsupported are usually particularly challenging.
- Allow periods of movement or repose, as appropriate, for reorganization of the whole body and all its sensory systems. Some older children and teenagers can seem to function quite well at their desk for extended periods of time, but they then need periodically to get up and move around, or to get into a horizontal position to relax and to re-charge their energy levels for the next exertions. They may also need periods in the horizontal position to reorganize their sensory systems using behaviors like leg kicking, hand flapping, shoulder shrugging, hyperventilating, or gazing at bright light.
- Observe for indications of under-arousal or over-arousal and know what to do about it (if the child cannot do this themselves).
- Think about the total demands made on the child by every activity in every situation (in other words, think multi-sensory). Many otherwise well planned activities fail because the child is being challenged or distracted by a sensory challenge that has not been noticed by the adults involved with them.
- Isolate lines of text (for example, large font on screen, typoscope) if necessary.

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