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1 author:

Brigita Kreiviniene
Klaipeda University

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Brigita Kreivinienė
Dolphin Assisted Therapy Center, Klaipėda University, Lithuania

Abstract

The objective of the submitted contribution is to describe one of the sensory dysfunctions – the dysfunction of the vestibular system. The vestibular system is a crucial sensory system for other sensory systems such as tactile and proprioception, as well as having tight connection to the limbic system. Vestibular sensory system has a significant role for further physical, emotional and psychosocial development. Descriptive method and case analysis are applied in literature based research methodology. These methods are most appropriate as far the vestibular dysfunctions are not always recognized in young age even though they are seen as high psychoemotional reactions (psychosocial behavior). The vestibular dysfunctions in young age can be scarcely noticeable as far more often they tend to look like “just high emotional reactions” as crying, withdrawal, attachment to mother etc. which could be sensed as a normal reaction of a young child. Detailed vestibular sensory dysfunction analysis is presented, as well as the explanation of the neurological processes, and predictions are made for the further possible interventions.

Keywords: *vestibular dysfunction, neuroscience, psychosocial behavior.*

Introduction

Some problems, such as broken bones, cerebral palsy or poor eyesight are obvious. Others, such as underlying poor behavior or slow learning are not so obvious. The issues, such as awkward walking, fear of other children, complicated socialization, unsecured feeling at school, avoidance of swings or climbing, slapping on the floor or to any other object, attachment to mother, sensitivity to changes in walking surfaces, preference on the same footwear (if changed, often falling/takes time to adapt), aggression to others, stimulation of head rotation, hyperactivity or constant distraction by light, smell, sound etc., and any others can have underlying sensory issues. Sensory issues are not so obvious and can affect many bright children therefore they are not so easily recognized (Ayres & Robbins, 2005).

Originally A. Jean Ayres being an occupational therapist with advance training of neuroscience and educational psychology developed a theory of sensory integration which sparked more research and generated more controversy than any other theory in occupational therapy. Her theory was based on hypothesizing and neuroscience was considered as a basis of evidence (Bundy, Lane, & Murray, 2002). There can be different variations of sensory disorders. Generally sensory integration disorders can be shared into three levels (Fisher, Murray, & Bundy, 1991):

- *First level or light sensory disorder* is barely noticeable by a nonprofessional. Child usually seems healthy and there cannot be made a distinction from other kids. Quite often such child with sensory disorders is described as more emotional, too active, choosy or low tolerating changes. It could be so that some of the sensory inputs (stimuli) are distracting, annoying, etc. Some of the children can be choosy to food, clothes, textures, etc. Such kid can feel anxiety because of the need to behave as other kids, even though it is too hard to keep up with other kids without sensory issues.
- *Second or average sensory disorder* is usually diagnosed when few of life spheres are touched. Child experiences difficulties in social life, demonstrates not appropriate psychosocial behaviour. Too aggressive, too avoiding of peers – such description is usually leading kids of this kind of sensory disorders. Often other spheres of life, such as everyday routine activities – dressing, tooth brushing, eating, etc. are disturbed, as well as lack of attention. Such primary issues lead to further issues at school and child experiences issues in school society, is afraid of new situations or changes. Child does not demonstrate inner drive to explore the surroundings or play because of the anxiety in new situations and avoidance of change.
- *Third or severe level of sensory disorder* disturbs the majority of life spheres of child. Such children usually have leading diagnoses such as delay in the development, autism or autistic behaviour. Usually such sensory disorder disturbs almost all life spheres of child and it is noticeable that child is avoiding some stimuli or seeking sensory stimuli constantly.

The issues related to vestibular sensory system are related to posture, balance, gaze stabilization, spatial orientation, preparation for “fight or flight” mode in emergency situation, physical and emotional security (Ayres & Robbins, 2005). Therefore, it is possible that in young age parents do not notice any vestibular dysfunctions as a primary issue of some occurred issues – like withdrawal from off-ground activities like climbing more than few steps on the ladder, not playing with other kids, rather sitting next to mother, tiredness or high-cry moments after visiting crowded places, etc. The vestibular sensory system dysfunction is very closely related to socialization and behavior issues. Many scientific studies agree that occurring vestibular disorders can affect people not only physically but also psychologically (Dix & Hallpike, 1952) as far vestibular dysfunction quite often is related to experienced stress and anxiety (Saman, Bamiou, Gleeson, & Dutia, 2012) or even panic symptomatology (Asmundson, Larsen, & Stein, 1998). It is related to an important role of limbic system on vestibular sensory system.

Receptors of the vestibular apparatus are located in the inner ear (Bundy & Murray, 2002). The inner ear is divided into two parts: first, the cochlea serving auditory function, and the second, non-auditory section. The non-auditory section of the human inner ear is the recognized center of motion sensors. This center provides information of body orientation and balance. Ability to orientate and preserve equilibrium with the surrounding environment is a basic prerequisite for normal existence (Schaaf & Lane, 2009). The vestibular system lays a foundation for the development of all other sensory systems from the early development (Ayres, 2005). Vestibular system plays a crucial role in the formation of relationship between the human’s gravity and physical world. It could be said that until something goes awry with visual, olfactory or auditory stimuli, you cannot appreciate the vestibular system (Baloh, Honrubia, & Kerber, 2011).

All our interactions with the surrounding world are through the actions of the motor system. Some of different patterns of motor behaviors are available at birth and later, up to 15 years of life the motor system continues to develop through maturation of neuronal circuitry and by learning through different motor activities (Purves, Augustine, Fitzpatric, Hall, LaMantia, McNamara, & Williams, 2004). The crucial ability of the vestibular system in human is to build a relationship with gravity – to remain upright and move through environment (Schaaf & Lane, 2009). In normal development children from the early years are delighted being moved through space – they experience *inner drive* to move – first to be rocked or walked, next to crawl and walk, and then to run, jump, and climb (Ayres, 2005). In demonstrating vestibular dysfunction no inner drive is observed in legs-off-the-ground activities, instead of wanting more, children are more likely to withdraw from the suggested activities, not discovering movement stimulation provided by playgrounds (Ayres, 2005). In practical observation the fear of falling off swings often can be exhibited as abnormal or after getting movement input hand gross motor function "turns off" and child can fall down or falls without demonstrating protection gestures.

Successful implications of sensory diet for vestibular dysfunction can have significant betterment in psychoemotional status and future social functioning. Quite often sensory disorder is seen as a field of only occupational therapists, however, it is proved that teamwork and holistic application of sensory integration techniques can lead to successful future development at any age group and neurological applications increases betterment in other spheres (Wilbarger & Wilbarger, 1991; Bundy, Lane, & Murray, 2002). Another aspect is that understanding sensory issues of child lets avoid labelling as if child is "not motivated enough", "lazy", etc. Even though sensory integration is a field of occupational therapists, other professionals such as special educators, speech therapists, social workers, psychologists must be acknowledged of sensory integration theory for recognizing the general features as well as for seeing the psychosocial aspects of behaviour from neurological perspective.

Therefore, the **aim** of this article is to present a case of a typical client with vestibular dysfunction and systemically present neurological explanation of such vestibular dysfunction: overview modulation possibilities and praxis relation with psychosocial behaviour.

The **research methods.** A descriptive method of methodological literature together with case analysis has been applied. Descriptive method is understood as a framework for understanding the neurological background for systemic view of the vestibular dysfunction and used for over viewing the common sense of vestibular sensory dysfunction seen via psychosocial behavior (Howarth, 2000).

Case analysis presentation. *A 4-year girl Katherine came with parents to the Dolphin Assisted Therapy center of the Lithuanian Sea Museum. Parents told that Katherine is highly emotional child, often crying with tantrums. High-cry moments are usually not related to any concrete issue or exhibited in not appropriate situations, such as in a group of children. At the age of 2 years she tried to be enrolled into kindergarten unsuccessfully. Most of her time spent in group Katherine was sitting aside and not interacting with other kids. Parents described Katherine's night situation as especially exhausting as far at the evenings she seems overtired (especially after any event, crowded place, etc.) but cannot fall asleep, if she falls asleep finally, there are high-cry moments during the night. Being in a bigger group of children she seems to be afraid of children so she stays together with mother. Parents told that when Katherine was smaller her high-cry moments were related to being in a moving car, now she is more tolerating being in a car. Parents think that she is awkward in walking, feeling* *unsecured in kindergarten, not swinging on swings. The other noticed issues observed: losing balance easily, clumsiness, tendency to hold mother's hand in any daily activity (sitting at the table; on the toilet, etc.), sensitivity to changes in walking surfaces, would prefer to wear the same footwear in all seasons and takes time to adapt (falling often) if it is changed. A sensory diet was presented to the parents, ten therapy sessions with dolphins in the water and twenty therapy sessions of sensory integration for vestibular dysfunction were held.*

Research Results

Neurological Explanation of Vestibular System: Structure and Functions

Katherine exhibited all typical vestibular dysfunction signs: postural control, balance (cannot hold it, afraid of losing balance, like in a group of children is scared to be bumped), possible gaze stabilization (when olfactory input in events is perceived as too overwhelming, therefore she feels too tired), spatial orientation (loses orientation in the dark), no emotional and physical security in any vestibular input, therefore typical reaction as well is "fight or flight".

It was mentioned that vestibular system is composed of the following components: the semicircular canals and the otolith organs, the utricle and the saccule (Bundy & Murray, 2002). Interaction of the semicircular canals and the otolith organs allows directional detection of movement. Both these organs have receptor regions containing hair cells, the actual receptors throughout this system (Schaaf & Lane, 2009). The otolith organs are responsible for static functions, the semicircular canals are responsible for dynamic functions. Vestibular sensory signal from the labyrinth of the inner ear provide direct information about rotations of the head and its orientation with respect to gravity. Semicircular canals and otolithic maculae are two types of vestibular transducer organs located within the labyrinth of the ear and respond to accelerations of the head in space. The three semicircular canals and the two otolithic maculae are stimulated by rotational and linear acceleration, respectively (Purves, Augustine, Fitzpatric, Hall, LaMantia, McNamara, & Williams, 2004; Lane, 2002; Schaaf & Lane, 2009). Therefore, when in Katherine case the control of posture and head and body position in space is needed, like swinging on swings, rolling on ball, etc., this information is processed by otolith organs (Lane, 2002). The hair cells of the otolith organs respond to sustained, slow movement of the head, linear movement, and head tilt. They are gravity receptors (Schaaf & Lane, 2009).

After the activation of vestibular system – semicircular canals and otolith organs – the semicircular canals activation takes place as a result of the movement of fluid in the canal (the membranous labyrinth contains fluid called endolymph) bending a structure called the cupula, into which the hair cells project. The semicircular canals are considered to be phasic receptors because they respond primarily to rotation, acceleration, and deceleration and are sensitive to changes in the rate movement (in general, balance and orientation in three-dimensional space). Activating the semicircular canals results in motor responses as far they are the rotational sensors of the vestibular system (Schaaf & Lane, 2009). If input is perceived in this system problematic, the balance losing and not being able to react with proper output may occur (as in Katherine's case – often falling without protective gestures or awkward walk, falling after footwear change, etc.). As far when stimulated semicircular canals, they participate in the control of the postural reflexes of the body and initiate compensatory eye movements in order to preserve the body balance and reference with respect to the environment (Schaaf & Lane, 2009).

The hair cells of the otolith organs respond to sustained, slow movement of the head, linear movement, and head tilt; they are gravity receptors. In Katherine's case any legs-off activities, like climbing, rolling on the ball, and running are related to the otolith system activation. The otolith, a gelatinous substance with small crystals (calcium carbonate grains in it) is supported over the macula by strands allowing a limited sliding travel. The macula is the receptor end of this otolithic organ, providing bed for the utricular branch of vestibular nerve. It also has sensory hairs imbedded and as far they are oriented in many different directions, any head movement activates some hair cells. Activating otolith organs provides maintained compensation and stabilization of the head and upper trunk in upright position (Schaaf & Lane, 2009).

The end result of this combination of semicircular canal and otolith receptors is that any movement of the head is detected; thus there is ongoing information to the central nervous system about head position in space and movement through space (Schaaf & Lane, 2009). If issue of the vestibular function is detected, the social behaviour can be seen via high emotional response "fight or flight" when for example, like in Katherine's case – when any dynamic and static inputs are detected.

Neurological Vestibular Processing: Receptors, Pathways and CNS structures

Analyzing Katherine's case it is important to note the receptors, pathways and CNS structures are involved into vestibular sensory processing in order to apply sensory diet, otherwise it is not possible to understand the process of neuroplasticity. The understanding vestibular input comes from semicircular canals which are phasic receptors, sending signal to central nervous system only responding to changes of movement and in contrast, from otolith organs which serve as the "tonic" receptor system always active, and always sending information to central nervous system – "informing" where one's head is in space (Lane, 20; Schaaf & Lane, 2009).

Information from both the semicircular canals and the otoliths is conducted to vestibular nuclei via vestibular-cochlear nerve (VIII). This nerve also closely adjoins the auditory (Sanders & Gillig, 2010). Vestibular-cochlear nerve VIII is responsible for collecting information from inner ear about head orientation and balance; cochlear branch is related to the reception/transmission of sound and hearing signals to/from ear. The vestibular nuclei also receive inputs from the cerebellum, proprioreceptors, and visual pathways, forming the foundation for integrating vestibular information with sensory and motor systems (Carter, Aldrige, Page & Parker, 2014; Schaaf & Lane, 2009). There are numerous projections from these nuclei (also called "business centers"), including to the spinal cord, thalamus, oculomotor nuclei, many parts of cerebral cortex and cerebellum (Schaaf & Lane, 2009; Ayres & Robbins, 2005).

There are four second order vestibular nuclei: the inferior, medial, lateral (Deiter's) and superior. All four nuclei are found beneath the floor of the fourth ventricle in the medulla and pons, lateral to the sulcus limitans. The pathways of vestibular system (Schaaf & Lane, 2009; Lincoln, 2016):

- Otolith projections to the lateral vestibular nucleus (location is in upper medulla). Psychosocial signs related to Katherine's case could be observed tiredness after walking on different surfaces as far it is related to higher input for activating muscles of legs and keeping balance. Descending projections synapse on alpha motor neurons in the lower cord activates Katherine's muscles of legs and helps to maintain upright balance. Also vestibulospinal synapses project to motor neurons in the upper cord in order to control neck and back muscles and guide head movement, which is crucial for stabilizing the head on the body as one moves through space. This lateral vestibule-spinal tract is ipsilateral and long (Schaaf & Lane, 2009; Lincoln, 2016).

- The superior vestibular nuclei (located in pons) project to the reticular formation and contribute to the reticulospinal pathway where together with the vestibulospinal pathway contribute to postural extension. The vestibular inputs to the reticular formation also contribute to arousal functions and reticular formation is important to cortical arousal (Schaaf & Lane, 2009; Lincoln, 2016). Therefore, vestibular deficit can be noticed when sensory input on vestibular system is taken to cerebral cortex from reticular autonomic system and arousal mechanisms (the reticular formation and its connections) via thalamus – the cortex is constantly alerted of environmental changes. In such input for Katherine higher heart rate and respiration were noticed as far reticular formation also regulates these functions (Carter, Aldrige, Page, & Parker, 2014).
- The ascending connections begin with semicircular canals inputs to the medial vestibular nucleus (also named as dorsal or chief vestibular nucleus, located in medulla) and continue to the oculomotor nuclei of cranial nerves III, IV, and VI. This is the basis for the vestibular-ocular reflex allowing us to accommodate for head rotations or angular movement (Schaaf & Lane, 2009; Lincoln, 2016). Any change of head position is sensed by the vestibular system, and a command is sent to the visual motor nuclei to move the eyes in the opposite direction. It should result in the vestibular-ocular reflex understanding that visual field appears stabile. Medial vestibule-spinal tract is bilateral and shorter than lateral (Schaaf & Lane, 2009; Lincoln, 2016).

In Katherine's case obvious vestibular-ocular reflex issue is noticed as high tiredness of busy environments, like shops, kindergarten, etc. where there are a lot of visual inputs. The vestibular-ocular reflex as well is crucial for nystagmus. Nystagmus is a combination of rhythmic slow and fast eye movements. This can be observed if the angle of rotation is large such that it cannot be compensated for by the motion of the eye in the orbit, the slow compensatory vestibular-induced eye movement is interrupted by quick movements in the opposite direction (Baloh, Honrubia, & Kerber, 2011). A post-rotary nystagmus was observed in Katherine as one of the important means in assessing the integrity of the vestibular-visual link (Schaaf & Lane, 2009). Such Katherine's deviation of nystagmus shows possible deficit in visual and auditory processing (getting lost in darkness, tiredness, fear of other children). The sensory systems involved: visual (receptors in eye: lens and retina) and auditory (receptors in ear: ear drum, stapes, hammer, and anvil; cochlea), the tracts involved in processing: auditory – vestibulocochlear nerve (cranial nerve VIII) with a function of receipting vibration, sound and localization of sound; visual – Optic nerve (cranial nerve II) with functions of visual acuity, visual fixation and visual perception (Curtis & Newman, 2015). In Katherine's case the vestibular nuclei get too much input (crowded places), in other situations it can be that vestibular nuclei get too little input or are not processing input correctly (Katherine's falling without protective gestures) (Ayres & Robbins, 2005). Vestibular system is as well closely interconnected with cerebellum. In this interactivity the reticular formation and three semicircular canals play significant role in equilibrium as well as creating awareness of where the body and head are in relationship to the environment. Cerebellar-vestibular connections also allow for eye movement reflexes; this input combines with visual information in a way that the cerebellum mediates reflexive responses of the body and head (Schaaf & Lane, 2009).

The vestibular system becomes integrated with proprioception and vision via connections through the thalamus to the cerebral cortex (conscious awareness of body position in space), and the auditory system via a thalamic projection. Vestibular-reticular connections influence the autonomic nervous system; activation of this link is responsible for vomiting, nausea, and changes in consciousness that may be associated with vestibular inputs (Schaaf & Lane, 2009).

Modulation and Vestibular Sensory System

Sensory modulation or sensory responsiveness is referred to as the ability to organize and regulate one's responses to sensory and motor stimulation in a graded and adaptive manner (Bundy, Lane & Murray, 2002). Modulation as a concept can be applied to any act that produces change or adjustment with intent to match social, biological or contextual condition. Without effective and efficient modulation of sensory signals in the brain, the person can experience overstimulation or have difficulties prioritizing to which sensation should direct. Modulation is perceived as one aspect of sensory processing, a process when activation of sensory receptors and transmission begins, also this transmission of information to the central nervous system is integrated with other input. The term *modulate* itself refers to the process of adjusting, it can be trait, any process or behaviour. The importance of modulation lies in setting the foundation for effective responsiveness. Like in Katherine's case, modulation should be applied for getting adaptive response in vestibular input, instead of fear and high-cry. Neuropsychologically, modulation reflects balancing excitatory and inhibitory inputs within central nervous system. Modulation of input is held as accomplished process when changes occur in synaptic transmissions at the cellular level. This can be observed behaviourally as far one can regulate and organize adaptive responses in reaction to sensory input (Lane, Lynn, & Reynolds, 2010).

Sensory reception takes place when sensation activates peripheral receptors. Activation of the receptor, also if intensity was sufficient (above threshold) or if applied repeatedly over time, triggers propagation of an action potential down the nerve fibre. All information about type of sensation, its intensity, frequency, and duration is transmitted to central nervous system. Intensity and frequency are reflected in a change in the number of action potentials transmitted to the central nervous system, and the ability of multiple receptor cells of varying thresholds in order to act in parallel to code intensity of stimulus (Lane, Lynn, & Reynolds, 2010).

Receptors in the vestibular structures in the inner ear are activated by the movement stimuli. Then, nerve fibres carry sensory information to the brainstem vestibular nuclei. Therefore, some modulation and integration could be there. Additionally vestibular nuclei receive input from proprioceptors and the cerebellum as well as from vestibular receptors. Reticular formation gets transmission from vestibular nuclei and interacts with and influences the processing of other sensation. Also transmission can continue into higher central brain structures such as the thalamus and the cortex where modulation takes place as well. At any level the sensory signals can be either amplified and/or dampened depending on central nervous system as far modulation and integration serves for producing behavioural responses that match different contexts. The thalamus is decided to be the key area of the brain to be responsible for modulation as far almost all sensory information reaches it directly and suppression of some senses may happen. The thalamus is not only connected to many brain regions but also filters sensory input as well as ensures that other areas of the brain would not be overwhelmed by sensory inputs (like in Katherine's case, when she cannot fall asleep when overtired or high-cry moments at nights, as far when the sensory inputs are over, the neurological system cannot "stop working" as far it was overwhelmed), and the most pertinent information is directed to the intended centers of the brain for processing and integration (Lane, Lynn, & Reynolds, 2010).

There are two main concepts in understanding the link between neural and behavioural modulation: *habituation* and *sensitization*. Habituation is understood as a capability to stop responding to a distractive stimulus (like loud sound) which does not have any consequences, and to understand that it is not salient or important. Habituation is important for being able to ignore irrelevant stimuli and focus on the relevant ones (Lane, Lynn, & Reynolds, 2010). Habituation occurs at different rates depending on stimulus qualities, repeated exposure to complex and behaviourally salient stimuli results in slower autonomic nervous system habituation than simple non-salient stimuli (Fischer, Furmark, Wik, & Fredrikson, 2000). People with faulty habituation are easily distracted because their nervous system accepts inputs as interesting and novel. Sensitization can be perceived as the opposite to the process of habituation because there is an increase in neural response to a stimulus, which is determined as novel, potentially important or potential harmful (the same in Katherine's case, vestibular input is always perceived as sensitization, therefore, frightful). Sensitization can be described as heightened awareness or responsiveness to a stimulus or class of stimuli for a period of time. Repetition is important for habituation, but for sensitization the main importance is put on the intensity of stimuli. Normally sensitization lasts for a short period and occurs only after emotional stimuli. From the perspective of modulation, sensitization means that the response of stimulus is enhanced (Lane, Lynn, & Reynolds, 2010).

Currently in the nosology there are three subtypes of sensory modulation disorders: *sensory over, under responsivity,* and *sensory seeking*. However there are studies (see Liss, Saulnier, Fein, & Kinsbourne, 2006) saying that sensory seeking is more a compensatory mechanism used to moderate high arousal levels at least in autism spectrum disorders, as far in both over and under responsivity populations sensory seeking were detected (Reynolds & Lane, 2008).

In Katherine's case her high-emotional reactions show her sensory over-responsivity (SOR) to the vestibular inputs. This is the most noticed form of disorder, tightly correlated with stress and anxiety (Reynolds, 2007). Usually it is characterized as quicker, more intense or longer response to sensation if comparing with individuals having typical responsivity. For example SOR within the vestibular system can be detected as gravitational insecurity (Katherine's intolerance to being in a car). It could be understood as sensitisation when vestibular input leads to anxiety and defensiveness (Lane, Lynn & Reynolds, 2010). However, there are studies proposing that there could be three theories in sensory over-responsivity and anxiety association: a) SOR is caused by anxiety; (b) anxiety is caused by SOR; or (C) SOR and anxiety are causally unrelated (Green & Ben-Sasson, 2010). Possible neurological explanation is poorly functioning otolithic vestibular processing and the exaggerated emotional response could be a result of the vestibular system's neurological connections to the limbic system (Lane, Lynn, & Reynolds, 2010).

Sensory Under-Responsivity (SUR) is characterized when response to normal sensory input is absent to diminish. Usually individuals with sensory under-responsivity need higher intensity of sensory input to respond or recognize the opportunities afforded to them in the environment. Under-responsivity with vestibular system could have impact due neurological connections between the vestibular receptors and the eye, and the role of the vestibule in sustaining muscle tone of the body. Sensory seeking is characterized when people need greater amounts of sensation than in typical cases. The needed sensation can be either with greater frequencies or longer durations. These behaviors can be noticed as immature or attention seeking (Lane, Lynn & Reynolds, 2010) like Katherine's case – attachment to the mother or unsecured feeling in group of children. The alternative explanation for sensory seeking behaviour is seen as a mean of calming (Lane, Lynn, & Reynolds, 2010).

In vestibular dysfunction often SOR is noticed in simple daily activities such as fear of height, emotional reactions to vertical orientation and linear movement activities, which could be related to postural deficit. In vestibular dysfunction, like in Katherine's case, a person experiences emotional response to antigravity movement which is exaggerated and out of proportion of risk. Such overreacting to particular sensory stimuli or experiencing higher than typical anxiety or arousal leads to typical behaviour, such as avoidance of sensory stimuli and the environment (Lane, Lynn, & Reynolds, 2010).

Neurologically sensory modulation refers to the mechanisms of habituation and sensitization imparted by the descending pathways of central nervous system (Reynolds, 2007). In case of vestibular dysfunction an aversive response to movement can be easily noticed as a response to gravitational insecurity. This may happen when nonthreatening vestibular stimulus causes autonomic nervous system reactions (Lane, Lynn, & Reynolds, 2010). In Katherine's case her usual behavioural reaction – irritation (sensitisation) to vestibular input can possibly be related to poor semicircular canal-mediated vestibular processing and strong autonomic nervous system response because of 1) vestibular system relation to limbic system responsible for emotions (and this is possibly impacted by Katherine's early development stage that she started to walk upright position and never crawled) and 2) limbic structures and the cortex ability to attach emotional significance of particular sensory signal 3) linking sensation with learned response (negative or positive reinforcement) as amygdala function (Lane, Lynn, & Reynolds, 2010). Vestibular input is transmitted via the thalamus and sends information to: a) amygdala for quick assessment and action (in SOR case – emotional content – fear, sends information for other areas for immediate bodily actions – distract, avoid, operates unconsciously), then to thalamus (trigger hormonal changes that make the body reaction to emotional stimuli – in SOR case possibly adrenalin, noradrenalin and cortisol (it is longer in producing, so not so easy to detect), that follows muscles contraction and increase of heart rate); b) sensory cortex for recognition and hippocampus (consciously perceived information and encoded to form memories, stored information confirming or modifying the initial response). Limbic system plays very important role in sensory information processing (Lane, Lynn, & Reynolds, 2010). One of limbic structures – amygdala acts as a store of good and bad memories, in SOR case it is working as "hard-wired" to fear vestibular input which is normally should not be perceived as dangerous and limbic system structures next to amygdala responsible for feelings of pleasure (like in normal situation when swinging) normally reduce activity in the amygdala and in cortical areas concerned with anxiety (Carter, 2014). This is very clearly seen in Katherine's case. Amygdala can be perceived as a region of multisensory convergence and integration as far it receives input not from the thalamus but also olfactory centres, regions in the brainstem that are associated with visceral sensation, and highly processed sensory information from cortical regions. Input from all sensory systems, the limbic system, the hypothalamus, the cerebellum, motor systems, the cortex goes to reticular formation. Therefore, almost everything is transmitted to central nervous system with the influence of reticular formation. In current understanding the reticular formation functions in the modulation of posture, automatic motor responses and muscle tone, and plays a role in autonomic and neuroendocrine functions – it is the mediation which is very important for modulation (Lane, Lynn, & Reynolds, 2010).

Ayres' Developmental Model and Modulation

The main aspects in modulation understanding by Ayres developmental model are neuro-physiological reactions and leading behavioural responses. Modulation helps to keep the balance of nervous system of both *inhibitory* (when we try to excite nervous system) and *excitatory* (when we apply reducing sensory strategies) influences on the brain. One of the most important aspects in modulation application is an "inner drive" (active participants in meeting new challenges and experiences) (Bundy & Murray, 2002) of a child as well as proper activities ("just right challenge"), adaptive response, active engagement and directing a child (Schaaf & Miller, 2005). Schaaf and Miller (2005) mention Ayres's developmental model and the following four basic principles important in modulation:

1. Sensimotor development is a substrate for learning.
2. Interaction of person with environment shapes the brain.
3. Nervous system has ability to change (neuroplasticity).
4. Sensory-motor activity is a powerful mediator of plasticity.

The developmental model of Ayres is stressing that the brain functions as a whole, and "the "higher-order" integrative functions evolved from and are dependent on the integrity of "lower-order" structures and on sensimotor experience" (Bundy & Murray, 2002, p. 11).

Praxis and Vestibular System

Praxis is a motor planning, it is the ability to conceptualize, plan and implement an unfamiliar motor action (Biel & Peske, 2009; Curtis & Newman, 2015). Usually in the vestibular disorders the vestibular intervention needs to involve tactile, proprioceptive, and visual inputs as far in most of studies vestibular system in treatment is seen as multisensory (Schaaf & Lane, 2009). Praxis is like ending product of input from all necessary systems and the brain. Good motor planning needs input from sense of touch, balance and movement, vestibular, vision and hearing (Biel & Peske, 2009). For the effective response all functions of the brain must function in harmony with one another (Ayres & Robbins, 2005). Praxis issues can be measured by Sensory Integration and Praxis Test (SIPT) where there are 17 overlapping types: motor-free visual perception, somatosensory, praxis, and sensorimotor or other standardised assessments such as: Bruininks-Oseretsky Test of Motor Proficiency, Miller Assessment for Preschoolers, Movement Assessment Battery for children, Developmental Test of visual-motor integration, Motor Free Visual Perceptual Test – revised, Test of Visual Perceptual Skills, and Sensory Profile (Patten).

Praxis Components, and Basis of Dysfunctions

Praxis includes three components: 1) *ideation* – generating idea of what you want to do (allow purposeful interaction with the environment); 2) *motor planning* – figuring out how person is going to do that (purposeful adaptive response involving the motor and sensory systems), and 3) *execution* – doing or carrying out the movement, putting plan into action (Roley, Mailoux, Miller-Kuhaneck, & Glennon, 2007).

Cortical area implements a function of ideation, prefrontal area is also involved, basal ganglia also thought to be in part related to the result of ideation. Basal ganglia are known as tightly associated with motor execution, cognitive and behavioral aspects of action. The location of ideation is not clearly known, however, it is known that areas of premotor and supplementary motor are not involved. These areas are important in planning, there they play important roles (Bundy, Lane, & Murray, 2002). Action is planned in the supplementary, premotor, and parietal cortices and then it is forwarded to motor cortex to execution (Carter, Aldridge, Page & Parker, 2014). Premotor and supplementary motor areas are involved in movement strategy and/or selecting movement tactics. When response is needed to the external factors, the lateral premotor area (polymodal) is activated. Supplementary motor areas primarily depend on proprioceptive inputs and are activated when there is a self-initiation, it is also associated with eyes and head orientation when planning bimanual and sequential movements as well as planning the projected action sequences. When quick, well-learned movement sequences are executed using primarily proprioceptive information independently to visual feedback monitoring, the medial system is predominating. Area 5 of the parietal cortex is another important structural joint of bilateral proprioceptive inputs from muscle, cutaneous, and joint receptors of the whole body sensory systems (Bundy, Lane, & Murray, 2002).

In voluntary action motor cortex provides a mechanism for executing movement. Primary motor cortex neurons receive an encode ongoing input about speed, velocity and direction of movement. This information comes from skin, joints, body muscles via thalamus, and intracortical projections from the somatic sensory cortex. Primary motor cortex transmits information to the muscles for executing via corticospinal and corticobular pathways. Movement also depends on information which travels from various areas of the brain to alpha motor neurons in the spinal cord. Motor system depends on continuous flow of sensory information before and during the task. Cerebellum is also involved and plays a major role in execution of coordinated movement (integration of movement and feedback) but less in direct control of movement. Basal ganglia receive inputs from supplementary motor areas and send it via the thalamus back, these functions are important when movements are complex and requires sequencing. Basal ganglia have crucial role in completion of movement sequences and the ventral system receives primary information from the limbic system (Bundy, Lane, & Murray, 2002).

Bundy, Lane, & Murray (2002) state that there are two levels of motor planning dysfunction: bilateral sequencing disorder and somatodyspraxia. Earlier than Bundy theory, Ayres theory documented in 1965 includes related to vestibular dysfunctions vestibular and postural deficits with integration of two sides of the body, right-left discrimination, midline crossing, and bilateral motor coordination (Roley, Mailloux, Miller-Kuhaneck, & Glennon, 2007). Ayres identified four patterns of dysfunction in praxis: 1) visuopraxis – this pattern refers to the ability skilfully plan actions and have dependence on vision (can be tested by visual perception and visual construction tests); 2) somatopraxis – this pattern reflects the ability to organize actions in relation to own body (can be measured by tasks requiring to imitate body positions and body sequences), 3) praxis on verbal command – it refers to planning of action as following verbal instructions, and 4) vestibular-postural-bilateral integration and sequencing pattern which refers to smoothly coordinated head, neck, eye movements in relationship to postural and bilateral control (Roley, Mailoux, Miller-Kuhaneck & Glennon, 2007). There are three types of praxis disorders: postural disorder, bilateral integration and sequencing (BIS) and somatodyspraxia (Roley, Mailloux, Miller-Kuhaneck, & Glennon, 2007).

Postural disorder is related to vestibular and proprioceptive processing issues. As Bundy, Lane & Murray (2002) state, this is not a practic disorder but can play a crucial role for deficits in BIS, as far the postural elements include extensor muscle tone, prone extension, proximal stability, ability to move the neck against gravity, equilibrium, also a postratory nystagmus could be an element. In Katherine's case, BIS was diagnosed, it is considered as low-average dysfunction. Katherine had SOR vestibular dysfunction where issues could be noticed during activities which stimulate adequate input from postural-ocular development vestibular-proprioceptive processing. Such problems could occur because of poor bilateral coordination skills, difficulties in planning and sequencing actions (riding a bike), and problems with completing projected actions involving timing and spatial skills. Quite often in Katherine's case it was seen that she can easily handle simple tasks but was experiencing problems in completing sequencing longer actions. Therefore, in Katherine's case such occupational playing was applied with giving just a right challenge to sequence one step more could be applied, for example catching, throwing a ball, rolling, sequencing in exercises. Another issue which appeared in Katherine (and is quite common in BIS) was experienced difficulty in coordinating upper and lower parts of the body, coordinating both sides of the body, developing trunk rotation, and developing skills in tasks that require timing and movement through space (Curtis & Newman, 2015). In BIS disorder intervention should be organized bearing in mind poor vestibular and proprioceptive processing, as it was in Katherine's case. It means that muscles give a command existing before the beginning a movement sequence (feedforward issue), after they are triggered and run their course without possibility of correction from sensory feedback The systems use anticipatory (or feedforward) control when there is no enough time to monitor and correct movement. Somatodyspraxia is a difficulty with both, feedback- (simple) and feedforward-dependant (difficult) motor tasks. Usually problems occur with whole spectrum of gross motor tasks. In somatodyspraxia the person is experiencing somatosensory (most often tactile) processing but poor vestibular and proprioperception processing is also present (Reeves & Cermak, 2002).

Conclusions

Sensory issues should be perceived as "hidden" issues which should be found by an occupational therapist and sensory diet should be prepared individually for adaptive response to the stimuli. Vestibular system is a crucial sensory system which has neurological interconnections with almost every part of the brain; therefore, in order to produce the most effective response, it needs to function in harmony with other systems.

The vestibular sensory system dysfunction is tightly connected to emotional responses or high-emotional reactions which are observed as "bad tempered behaviour". Unfortunately an important aspect must be perceived that many scientific studies discuss that vestibular dysfunction more often occurs in persons not only physically but psychologically or can have psychiatric consequences. It is related to very high emotional reactions – stress experience and anxiety.

Understanding neurological aspects of the vestibular dysfunction gives opportunity to observe human behaviour through another angle. As well as it is important to note traditional Ayres' theory that at any age human nervous system has ability to change because of neuroplasticity.

References

Asmundson, G. J. G., Larsen, D. K., & Stein, M. B. (1998). Panic Disorder and Vestibular Disturbance: An Overview of Empirical Findings and Clinical Implications, Journal of Psychosomatic Research, *44* (1), 107-120.

Ayres, J. (not dated). *Description of the Sensory Integration and Praxis Tests for Parents. Taken from the SIPT Manual published by Western Psychological Services. Sensory Integration and Praxis Tests (SIPT).* Retrieved from: http://childrenstherapy.org/sensory-integration-praxis-tests/

Ayres, A. J., & Robbins, J. (2005) *Sensory Integration and the Child. Understanding Hidden Sensory Challenges. 25th Anniversary Edition*. Los Angeles CA: Western Psychological Services.

Baloh, R. W., Honrubia, V., & Kerber, K. (2011). *Baloh and Honrubia's Clinical Neurophysiology of the Vestibular System.* Oxford university press, Inc.

Bundy, A. C., & Murray, E. A. (2002). Sensory Integration: A. Jean Ayres' Theory Revisited. In: A. C. Bundy, S. J. Lane, & E.A. Murray, (Eds.), *Sensory integration: theory and practice* (pp. 3-29). Philadelphia: FA Davis Company.

Carter, R., Aldridge, S., Page, M., & Parker, S. (2014). *The Brain Book. 2nd Edition*. London: Dorling Kindersley Limited.

Curtis, K. A., & Newman, P. D. (2015). *The PTA Handbook: Keys to Success in School and Career for the Physical Therapist Assistant. 2nd Edition*. Thorofare, NJ: SLACK incorporated.

Dix, M. R., & Hallpike, C. S. (1952). The Pathology, Symptomatology and Diagnosis of Certain Common Disorders of the Vestibular System. *Proceedings of the Royal Society of Medicine, 45* (341), 341-354.

Fischer, H., Furmark, T., Wik, G., & Fredrikson, M. (2000). Brain Representation of Habituation to Repeated Complex Visual Stimulation Studied with PET. *NeuroReport, 11*(1), 123-126.

Fisher, A. G., Murray, E. A., & Bundy, A. C. (1991). *Sensory Integration: Theory and Practice*. Philadelphia.

Green, Sh. A., & Ben-Sasson, A. (2010). Anxiety Disorders and Sensory Over-Responsivity in Children with Autism Spectrum Disorders: Is There a Causal Relationship? *Journal of Autism and Developmental Disorders, 40* (12), 1495-1504.

Howarth, D. (2000). *Discourse.* Buckingham (Philadelphia): Open University Press.

Lane, S. J. (2002). Structure and Function of the Sensory Systems. In: A. C Bundy, S. J. Lane, & Murray (Eds.), *Sensory integration: theory and practice*: 2nd edition (pp.35-70). Philadelphia: FA Davis Company.

Lane, Sh. J., Lynn, J. Z., & Reynolds, S. (2010). Sensory Modulation. *A Neuroscience and Behavioral Overview. OT Practice, 15* (2), CE-1-8.

Lincoln, G. (not dated). *Vestibular System: Pathways and Reflexes*. Retrieved from: http://neuroscience.uth.tmc.edu/s2/chapter11.html

Liss, M., Saulnier, C., Fein, D., & Kinsbourne (2006). Sensory and Attention Abnormalities in Autistic Spectrum Disorders. *Autism, 10* (2), 155-172.

Patten, N. (not dated). *Dyspraxia from an Occupational Therapy perspective.* Retrieved from: http://dyspraxiafoundation.org.uk/downloads/dyspraxia_and_Occupational_Therapy.pdf

Purves, D., Augustine, G. J., Fitzpatric, D., Hall, W. C., LaMantia, A. S., McNamara, J. O., & Williams, S. M. (2004). *Neuroscience, 3rd ed*. Sinauer Associates, Inc.

Reeves, G. D., & Cermak, Sh. A. (2002). Disorders of Praxis. In: Bundy, A. C., Lane, S. J. and Murray, E. A. (Eds), *Sensory integration: theory and practice* (pp.75-95). Philadelphia: FA Davis Company.

Reynolds, S. E. (2007). *Stress and Anxiety in ADHD: Links to Sensory Over-Responsitivity.* Doctoral thesis, Virginia Commonwealth University.

Roley, S. S., Mailloux, Z., Miller-Kuhaneck, H., & Glennon, T. (2007). Understanding Ayres Sensory Integration. *OT Practice, 12* (17), CE-1-8.

Saman, Y., Bamiou, D. E., Gleeson, M., & Dutia, M. B. (2012). Interactions between Stress and Vestibular Compensation – A Review. *Frontiers in Neurology, 3,* 116.

Sanders, R. D., & Gillig, P. M. (2010). Cranial Nerve VIII. Hearing and Vestibular Functions. *Psychiatry, 7* (3), 17-22.

Schaaf, R. C., & Lane, Sh. J. (2009). Neuroscience Foundations of Vestibular, Proprioceptive, and Tactile Sensory Strategies. *OT Practice, 14* (22), CE-1-8.

Schaaf, R. C., & Miller, L. J. (2005). Occupational Therapy using a sensory integrative approach for children with developmental disabilities. Mental Retardation and Developmental Disabilities. *Research Reviews, 11*, 143-148.

Wilbarger, P., & Wilbarger, J. (1991). *Sensory defensiveness in children 2-12*. Santa Barbara.

VESTIBULAR SENSORY DYSFUNCTION: NEUROSCIENCE AND PSYCHOSOCIAL BEHAVIOUR OVERVIEW

Summary

Brigita Kreivinienė, Dolphin Assisted Therapy Center, Klaipėda University, Lithuania

Some problems, such as broken bones, cerebral palsy or poor eyesight are obvious. Others, such as underlying poor behavior or slow learning are not so obvious. The issues, such as awkward walking, fear of other children, complicated socialization, unsecured feeling at school, avoidance of swings or climbing, slapping on the floor or to any other object, attachment to mother, sensitivity to changes in walking surfaces, preference on the same footwear (if changed, falling often/takes time to adapt), aggression to others, stimulation of head rotation, hyperactivity or constant distraction by light, smell, sound etc., and any others can have underlying sensory issues. Sensory issues are not so obvious and can affect many bright children therefore they are not so easily recognized (Ayres & Robbins, 2005).

The issues related to vestibular sensory system are in general related to posture, balance, gaze stabilization, spatial orientation, preparation for "fight or flight" mode in emergency situation, physical and emotional security (Ayres & Robbins, 2005). Therefore, it is possible that in young age parents do not notice any vestibular dysfunctions as a primary issue of some occurred issues - like withdrawal from off-ground activities like climbing more than few steps on the ladder, not playing with other kids, rather sitting next to mother, tiredness or high-cry moments after visiting crowded places, etc. The vestibular sensory system dysfunction is very closely related to socialization and behavior issues. Many scientific studies note that occurring vestibular disorders can affect people not only physically but also psychologically (Dix&Hallpike, 1952) as far vestibular dysfunction quite often is related to experienced stress and anxiety (Saman, Bamiou, Gleeson& Dutia, 2012) or even panic symptomatology (Asmundson, Larsen&Stein, 1998). It is related to limbic system important role on vestibular sensory system.

Therefore, the objective of the submitted contribution is to describe one of the sensory dysfunction - the vestibular system. Descriptive method and case analysis are applied in literature based research methodology. These methods are most appropriate as far the vestibular dysfunctions not always are recognized in young age even though are seen as high psychoemotional reactions (psychosocial behavior). The mostly common vestibular dysfunction case of 4-year girl Katherine is presented in the article. In Katherine's case her vestibular dysfunction signs are related to postural control, balance (such as cannot holding it, being afraid of losing balance, or being bumped by other children), gaze stabilization issue (when olfactory input in events is perceived as too overwhelming, therefore she feels too tired), spatial orientation (loosing orientation in dark), no emotional and physical security in any vestibular input, and typical reaction - "flight or flight". The results describe neurological pathways of vestibular input and defect possibility over viewing central nervous system structures involved in the process. In such cases as vestibular dysfunction sensory modulation process has high importance because of the ability to organize and regulate Katherine's responses to sensory and motor stimulation in a graded and adaptive manner instead of high-cry moments, praxis is analyzed seeing Katherine's vestibular dysfunction as Bilateral sequencing disorder.