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A REVIEW OF THE INTERRELATIONSHIP BETWEEN VESTIBULAR DYSFUNCTION, MOTOR AND LEARNING DISABILITIES AND THE REHABILITATION THEREOF

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ABSTRACT

The aim of this literature review was to determine whether there is a relationship between the vestibular functioning and neuro-motor development of children, if deficiencies in vestibular function can be rehabilitated by means of a motor rehabilitation programmes and what the nature of such activities and programmes will be. It was also aimed to determine what tests are used to evaluate vestibular function and to identify those that will have use in practical settings. After examining 130 articles, they were reduced to 41 from which the relevant information was retrieved. A direct relationship was indicated between balance problems and vestibular functioning, while poor motor coordination, postural deficiency, learning problems and dyslexia were also associated with dysfunction of the vestibular system. Different tests evaluating vestibular loss were identified of which some can be used successfully by practitionars. Various programmes and activities were identified to successfully rehabilitate vestibular function. For better understanding of the contribution of the vestibular system to motor development of children, further research on the relationship of the different semi circular canals with different motor functions, the effect of rehabilitation focused on the functioning of a specific canal, and the effect of different rehabilitation programmes on different vestibular deficiencies are suggested.

Key words: Vestibular dysfunction; Motor development; Learning disabilities; Posture; Rehabilitation and exercises.

INTRODUCTION

Kaga (1999) indicated that the vestibular system, in combination with other systems, plays an integral role in the normal development of a child. This researcher indicates that a child who suffers from vestibular loss in both ears, will most probably have impairment of postural control and locomotion, although other delays in development are also seen. Gross motor functions such as sitting, walking and head control are usually impaired (Kaga, 1999) and these delays and inabilities are generally the cause of other problems experienced with equilibrium (Guyton & Hall, 2000), spatial orientation (Pienaar, 2004) and poor school performance (Reynolds *et al.*, 2003). However, it is indicated that early exposure to intervention programmes concerning the vestibular system and its associated problems, can improve or even eliminate these deficiencies (Hain, 2003).

In this review article, the aim was to determine if there is a relationship between the vestibular system and neuro-motor development of children, if deficiencies in vestibular function can be rehabilitated by means of a motor rehabilitation programme and what the nature of such activities and activity programmes will be. A further aim was to identify practical tests that can be used to determine vestibular deficiencies. A short introduction of the physiology of the vestibular system was deemed important in order to understand the major role of the vestibular system in the functioning of the body.

PHYSIOLOGY OF THE VESTIBULAR SYSTEM

The vestibular system consists of a number of structures that are found on both sides of the head. These structures are the perifere end organs which are part of the inner ear (connected to the semicircular canals, the utricle and saccule), the vestibular nuclei, the vestibular afferent and efferent and the 8th cranial nerve connection (Pienaar, 2004). Rotation of the head and linear motion are detected by the two receptor organs, the semicircular canals and the vestibule that sense movement and static position.

The vestibular system which is located in the inner-ear consists of two main parts, three semicircular canals filled with fluid and two vestibular sacks also filled with fluid (Goddard, 1996). Hair cells are located inside these organs and when body movement sets the fluid in these organs in motion, the hair cells trigger nerve signals to be sent to the brain (Levinthal, 1990). The three semicircular canals (medial, lateral and horizontal) sense movement in each of the three spatial planes by lying perpendicular to each other. The crista ampullaris, the collective name for the movement hair cells, lies at the base of these canals (Levinthal, 1990). When the head is moved in a specific plain, the endolymph flowing inside the canals stimulates the appropriate movement of hair cells in a small swelling at the base called the ampulla. When the head is in a static position, it is sensed by the position of the hair cells of the utricle and saccule of the vestibule. Each tuft of hair cells is polarized, meaning that when forced to one side, it is excited while when forced to the other side, it will become inhibited. The position of the hair cells is mirrored on the two sides of the head. Thus, when the head is moved in a specific plane, the hair cells on the one side will be excited while those on the other side will be inhibited, causing the appropriate response to the movement (Molavi, 1999).

According to Pienaar (2004) the vestibular system is in close relation with the vestibular nuclei, reticular formation, cerebellum and the parietal and temporal lobes of the cortex. When the hair cells are stimulated a nerve impulse is created which travels over the vestibular nerve and sends information to the 3rd, 4th and 6th nerve connection to control eye movements and the vestibulospinal nerve tract for reflexive posture adjustments to the head, limbs and trunk. This will cause muscle tone and will provide a straight position against gravity. Information is also sent to the temporal lobe of the cortex, the thalamus, for automatic adjustments and to the brainstem and cerebellum where all motor and sensory information are integrated for body movements.

A second role of the semicircular canals is to keep the eyes fixed while the head moves around the eyes in order to enable the eyes to compensate for head movements. The three pairs of muscles that control the eyes are the medial and lateral rectus, the superior and inferior rectus and the inferior and superior oblique (Molavi, 1999). Each semicircular canal and the plane that it functions in, interacts closely to a single muscle pair and its plane of movement. This entire compensatory reflex is called the vestibule-ocular reflex (VOR) (Molavi, 1999). When the head moves to one side, the VOR is responsible for stable images on the retina by generating smooth eye movements in the opposite direction than the head movement. The vestibular signals play an integral role in the creating of these eye movements (Raymond & Lisberger, 2000).

According to Bent *et al.* (2002), vestibular information is integrated differently during the execution of a step when the eyes are closed, compared to when the eyes are opened. This indicates the important input of sight and the integration of the vestibular and ocular systems with each other during motor execution.

The vestibulospinal tract consists of nerve fibres that descend the entire length of the spinal cord, and which are responsible for the reflexive adjustments in the neck, trunk and limbs that are necessary for maintaining balance (Levinthal, 1990). This pathway functions in close relation to the somatosensory-spinal pathway, the trigger for responses to body displacements and influence and interact with each other (Horak *et al.,* 2001).

The mechanisms for executing voluntary movements can be divided into two classes, the pyramidal and extrapyramidal motor systems. The functional core of the extra pyramidal system is the cerebellum (Levinthal, 1999). In combination with feedback systems from other brain parts, the cerebellum is able to control and integrate complex motor acts of the body**.** This information will be carried through the corticocerebellar tract, through branches of the vestibular nerve from the inner ear and through the spino cerebellar tract from the muscle spindles. This information from the cerebellum will be integrated into a movement, influenced by the level of tension in the muscles (muscle tone) and from information provided on voluntary movement from the inner ear (Levinthal, 1990).

FACTORS CONTRIBUTING TO VESTIBULAR DYSFUNCTION

Central nervous system vestibular dysfunction can be caused by brain disruption, especially in the area of the posterior fossa and the brain stem, usually including the vestibular nucleus (Whitney & Unico, 2001). High-risk sport such as boxing, rugby, ice hockey, football, hockey and basketball are most common causes of mild head injuries that can cause damage to the end organ (Whitney *et al*., 2001). Head trauma, infection, baro trauma (sudden, drastic changes in air pressure, or water pressure in the case of diving), a genetic predisposition, congenital defect, birth injury, excessive straining (with prolonged vomiting or weightlifting) and whiplash are all indicated causes of vestibular disorders (Blomgren, 1989). Levinson (1988) also stated that a wide range of clinical evidence indicates that injury to the cerebella-vestibule system can be the result of traumatic, metabolic, degenerative, toxic, infectious or allergic reasons.

Head injuries and ear infections are common in childhood (Blomgren, 1989) and studies suggest that up to 73% of head injuries result in some ear damage. In addition, Blomgren (1989) indicates that dizziness among an estimated 85% of the entire population originates in the vestibular system. This researcher also indicates that certain drugs, notably amioglycoside antibiotics such as Tobramycin and Gentamycin, can also cause damage to the ear, ototoxicity or "toxic to the ear" effects, although this is usually associated only with high doses given intravenously.

RELATIONSHIPS BETWEEN VESTIBULAR FUNCTIONING AND DEFICIENCIES

Vestibular disorders include injuries to the vestibular system or the brain. These involve the semicircular canals which detect rotational movement of the body, the otolith organs which detect linear movement and orientation with respect to gravity and the cochlea which is the hearing organ (Whitney & Unico, 2001). Efficient cognitive learning and dyslexia, posture control, muscle tone, co-contraction, equilibrium reactions, eye pursuits, coordination and balancing problems are all associated with vestibular dysfunction (Nashner, 1970; Ayres, 1976; Levinson, 1988). Each of these relationships will be discussed in more detail in the following section.

Ayres (1976) hypothesized that the vestibular system plays a role in efficient cognitive learning by contributing to the development of hemispheric specialization. According to Levinson (1988), dyslexia was first defined in 1896 and was thought to be a defect in the cerebral cortex or the thinking brain, involving incomplete cerebral dominance. Multi-sensory interventions for the treatment of dyslexia were therefore proposed (Orton, 2000). In the 1960's, Levinson found cerebella-vestibule-localizing signs in dyslexia and began to suspect that it was a cerebella-vestibule dysfunction. This finding indicates that the different electrical patterns found in the cerebral cortex were secondary in nature (Levinson, 1988).

The reflex system and the vestibular system act together as substrata on visual-perception and ocular-motor movements (Goddard, 1996). Eye movements effect how a person can follow words in a book. Levinson's hypothesis that cerebella-vestibular impairments in dyslexics result in alternations in the interconnecting cerebral mechanisms (Levinson, 1988) can in turn be supported by this. In mammals, the ear has become highly developed and divided into two structures and signals are transmitted via the eighth cranial nerve to the cerebellum and then to the cerebral cortex (Goddard, 1996). Localized cortical neurological signs and an absence of cerebral cortical neurological signs were found by Levinson when he was examining dyslexics (Levinson, 1988), supporting the notion that dyslexia is an inner-ear or cerebella-vestibular dysfunction. Hence, the messages that are sent to the cerebral cortex are scrambled by this dysfunction and could conceivably cause different electrical impulses for dyslexics as seen in EEG studies of the cerebral cortex. A thorough evaluation of the vestibular system is therefore important in the treatment of the child with learning disabilities (Ayers, 1976).

There is also growing evidence demonstrating a relationship between middle-ear disease with hearing impairment and delays in the development of speech, language and cognitive skills (Levinson, 1988). These findings are compatible with a wide range of clinical evidence indicating that any injury to the cerebella-vestibule system (traumatic, metabolic, degenerative, toxic, infectious, or allergic) may result in acquired dyslexia symptomatology (Levinson, 1988).

The vestibular receptors have been anatomically divided into two categories, static (otolithic) and dynamic (semicircular canal) receptors, which work together to provide postural regulation. These receptors activate postural responses of both a static (tonic) and dynamic (phasic) nature through efferent connections with intrafusal and extrafusal muscle fibres. The otolithic functioning was differentiated from semicircular canal functioning by Nashner (1970), an aeronautical engineer. This researcher had four subjects, three normal adults and one adult with bilaterally transected eighth cranial nerves, who were asked to stand on a platform having two degrees of freedom of movement. Ankle reaction torque and body angle of each subject were measured as feedback from vision and the exteroceptive mechanism (pressure and joint receptors) was alternately eliminated. He paired the semicircular canals with the exteroceptive mechanism and demonstrated their low threshold and rapid (frequencies greater than 0.1Hz) detection of body sway. High threshold and slow (frequencies less than 0.1Hz) correction was attributed to the otolith organs and the visual system. Nashner maintained that the semicircular canals are responsible for the immediate correction of posture as the body begins to fall and that the design of the semicircular canals makes them unable to respond to static, low frequency movements. In contrast, the otolith is sensitive to both static conditions and linear acceleration, receives ambiguous information at high frequencies and requires additional processing in order to respond (Nashner, 1970). Ayres (1976) has described postrotary nystagmus and prone extension in such a manner that they apparently reflect dynamic and static aspects of vestibular functioning respectively.

Bundy and Fisher (1981) stated that theorists and researchers have studied muscle tone, co-contraction, equilibrium reactions and eye pursuits and each has been attributed to the vestibular mechanism. Impulses from the vestibular nuclei regulate muscle tone, especially the muscles that are involved in the maintenance of posture. If the vestibular system is disorganized, hypo- muscle tone will be the result and such a child will fatigue easily (Cheatum & Hammond, 2000; Pienaar, 2004).

On the basis of Nashner's model, co-contraction and muscle tone may be considered to be primarily static in nature, while equilibrium reactions and eye pursuits are primarily dynamic. It was also found that the vestibular mechanism influences extensor rather than flexor muscle tone (Ottenbacher, 1978).

In Ayres opinion, the maintenance of prone extension resulted from impulses conveyed via the vestibulospinal tract and was, therefore, assumed to be a static vestibular function (Ottenbacher, 1978). According to Wilson (1975), more vestibular input is carried via the vestibulospinal tracts to the extensors of the neck and the upper trunk than to the lower trunk. As a result of this study, they concluded that the ability to perform equilibrium sitting by itself or in conjunction with an inability to do equilibrium kneeling and ability of the eyes to cross the midline can be used to predict children's abilities for prone extension (Bundy & Fisher, 1981). These researchers wanted to prove that prone extension could primarily be used as a vestibular test, but found that it could only be used as an indication thereof and that more research is necessary in this regard.

The relationship between the vestibular, visual and proprioceptive systems plays an important role in acquiring certain reflexes and an adequate body posture. However, these functions are essential for the development of motor skills (Horak *et al.*, 1988). Children who had early brain damage frequently present with slower, atypical motor development and babies show evidence of disorders in muscular tone and posture development (Vatovec, 2001). Eviatar and Eviatar (1978) also believe that damage to the vestibular apparatus is attributed to the delay in posture development in infants with congenital hearing disorder. In infants at risk of brain damage, a correlation between the degree of neurological risk and the frequency of vestibular disorders has been confirmed (Vatovec, 2001). The vestibular apparatus, in combination with visual and muscular cues, is also essential for maintaining body posture and controlling eye movements (Levinthal, 1990) and also informs the brain of the position of the head in space.

Movement of the head in different planes relative to gravity is sensed by the end organs and signals are transducted by them to control reflexes responsible for maintaining stability of images on the fovea of the retina and postural control (Schubert & Minor, 2004).

Dysfunction of the eyes, poor posture, poor balance and inability to orientate oneself in space (conscious perception of space) is also related to vestibular dysfunction (Horak *et al*., 1988). Researchers (Vatovec, 2001) who studied the condition of the vestibular apparatus in infants at risk of brain damage, found that this population more frequently presented with balance disorders and that the degree of neurological dysfunction was correlated with the extent of vestibular apparatus damage (Vatovec, 2001).

Horak *et al*. (1988) indicate that dysfunctioning of the vestibular system can lead to poor motor coordination, poor posture and learning disabilities. Vestibular functioning can also be directly connected with balance problems (Horak *et al*., 1988). According to researchers (Ayers, 1980; Horak *et al.,* 1988) balance and coordination problems are connected with abnormalities of the peripheric vestibular system input (Pienaar, 2004). It can also interfere with basic sensory functions that are necessary for the development of lateral perceptual cognitive processes, such as reading (Pienaar, 2004). Dysfunction of the vestibular system can cause problems with dexterity and ocular motor control, delayed gross motor development, visual perception and a decrease in conceptual understanding of posture (Pienaar, 2004). Levinthal (1990) substantiates that damage to the cerebellum and/or the vestibular system can cause disturbances in balance, muscle tone, muscular coordination, spatial orientation and eye functions.

REHABILITATION OF VESTIBULAR DYSFUNCTIONS

Vestibular rehabilitation refers to the use of exercises and activities to reduce vertigo (the sensation of the environment or person moving when they are actually not) and increase independence in patients with impairments of the vestibular system (Cohen & Kimball, 2004). The following discussion will explore factors which will have an influence on the rehabilitation process, symptoms, tests and recommended activities and programmes.

General signs and symptoms of vestibular dysfunction

Williams (2003) highlighted warning signs of vestibular dysfunction in young children. They are poor head control, slow hand placing, resisting change in position and delay in fine and gross motor skills. They also appear clumsy, almost as if walking in the dark, are uncomfortable in the upright and sitting positions, have a tendency to fall and have odd body postures. Other indicators of vestibular dysfunction are delays in developmental milestones, eye wobbling or nystagmus, worsening of nystagmus by sudden head movement, gait and stance disturbances when walking in line, veering to one side, problems with heel to toe walking, standing on one leg, hopping in a circle, standing on a tilt board or foam rubber and while marching on the spot or in line. According to Williams (2003) all these manoeuvres are worsened by eye closure.

There are two commonly identified vestibular disorders, Benign Paroxysmal Positional Nystagmus (BPPN) and Perilymph Fistulas (PLFs), (Blomgren, 1989). BPPN is usually caused in the young by head trauma which damages the semicircular canals and associated balance organs in the inner ear and is probably the most common. This damage causes distortion in the sensory messages sent from the balance organ to the brain. It usually worsens in certain positions, especially when the head is tilted backwards and turned to the affected side. Dizziness, vertigo, nausea, fatigue, anxiety, tension, visual stress (difficulty focusing, eye muscle fatigue and headaches), memory and concentration problems, increased motion sickness and disorientation in the darkness are some symptoms that can be experienced according to Blomgren (1989).

Barton (2000) also highlighted typical signs and symptoms of this condition. He found a latency of several symptoms when the person changes position before the spinning sensation starts, a pronounced spinning-sensation intensity immediately after change of position, then decreasing, and that the duration of the spinning sensation is never more than one minute. Patients also showed torsional up-beating eye movements, although the eyes might also beat torsionally and down or horizontally and nystagmus reverses directions with change in position, with a lessening intensity of the response with repeated exposure to the offending movement. Symptoms are found to be worse in the morning, often occurring when starting to rise from bed in the morning or when lying down at night. They also experience vertigo when bending, lying flat or turning the head and show mild imbalances on high-level balance tasks. Perilymph fistulas (PLFs) are breaks or leaks in the tiny membranes that separate the fluid-filled inner ear from the normally air-filled middle ear and are frequently associated with hearing loss. It can cause nausea, dizziness, vertigo, as well as tinnitus (ringing in the ears), fluctuations in hearing and sensations of fullness and pressure in the ears (Blomgren, 1989).

Levinson (1994) reported most common cerebella-vestibular neurological signs which were found when blind neurological studies were done by Carter and Gold, involving dyslexics. These are impaired succession movements of the fingers, graph motor in coordination, i.e. (poor letter formation and spacing), immaturity and distortion of Bender Gestalt, difficulty drawing letters, difficulty with fine motor or small muscle coordination, clumsy and awkward coordination, i.e. (difficulty catching, kicking and throwing) and difficulty hopping, preplans and slurring of speech (Levinson, 1994).

Two forms of dysfunction of the vestibular system are also indicated to interfere with learning and behaviour, namely hypo and hyper-vestibular simulation (Cheatum & Hammond, 2004). A child with a hypo-active vestibular system experiences difficulties with integrating the two sides of the body, finds it difficult to coordinate the right and left sides and gets confused with instructions and directions, especially when not having time to think. Confusion of left and right, of "b" and "d", reading of words from behind, problems with reading and mathematics, frustration and an inability to handle stress are learning related symptoms reported by researchers (Pienaar, 2004). Problems with throwing and catching a ball, maintenance of the TPL (tonic prone labyrinth reflex), trouble lifting of the head, arms and legs together and difficulty to engage in dance activities because of poor upper and lower limb coordination and a lack of rhythm are also reported (Pienaar, 2004).

Children who have an hyper-active vestibular system dislike not having their feet touching the ground, have an unnatural fear of falling, are afraid of heights, dislike to be upside down, don't like handstands or moving apparatus, take time in learning to climb up or down stairs and make use of the railing instead of their own posture (Pienaar, 2004). In addition, they dislike climbing activities or jumping from heights and although it seems as if space is judged inaccurately, they can't handle the movement in that space (Ayers, 1980; Pienaar, 2004).

Testing of vestibular function

A variety of clinical tests found in the literature are available for the assessment of vestibular dysfunction. Sparto and Furman (2000) tabulated most of the tests which are displayed in Table 1.

TEST	DESCRIPTION	CRITERIA FOR A NORMAL RESULT
Caloric Test	Patients lay supine with the head inclined upward 30 degrees. Warm/cold air/water is placed in the ear canal alternately. Electrodes placed around the eyes record eye movement. Stimuli are produced by irrigating the external auditory canal with 10 ml of 0 degrees water for 10 seconds without visual fixation. Optokinetic nystagmus (OKN), smooth eye pursuit, and saccades are recorded separately (Eviater & Eviater 1979, Honrubia *et al.* 1980).	This is the only test that can determine which ear contains the lesion. The symmetry and intensity of the responses are calculated and compared with those of normal subjects.
Ocular motor screening	The person sits in a darkened room with goggles on and fixates on a target while watching vertical lines move in front of him or her. Electrodes surrounding the eyes record eye movements, which are analyzed for accuracy and timing (Sparto, Whitney & Furman, 2000).	Abnormal responses might indicate dysfunction of the central nervous system (brain).
Hand-operated rotating chair	A session comprised of 10 spins in a hand-operated rotating chair, fitted with a velocity indicator and located in a darkened room. For two spins (one clockwise, one counterclockwise), the child is seated upright with the head tilted forward by 30º. The child is then placed in a right-side lying position reversed for alternate spins. This procedure is then repeated with the child in a left side-lying position. The positioning of the child during rotation is controlled by seating the child on an adult's lap or placing the child in a carry basket with pillow support (Kenneth, Over; 1980).	When the patient's head stops, his eyes should be stable. If there is an asymmetry in the vestibular input to the cerebellum, then one will see a nystagmus beating away from the detective side.

Positional test	The patient is asked to lie on his or her back, head right, then head left, and then to lie completely on the left and right sides. The examiner observes for nystagmus (Sparto, Whitney & Furman, 2000).	Nystagmus indicates vestibular dysfunction.
Rotational testing	The patient sits in a darkened room with electrodes surrounding his/her eyes and is moved to the right and left (slowly) in a rotating chair while his or her eye movements are recorded (Sparto, Whitney & Furman, 2000).	Asymmetrical responses in the right and left ears indicate a positive test.
Posturography	The patient stands under 6 different sensory conditions. Forceplates record the amount of sway that the patient experiences under increasingly complex visual and somatosensory conditions. Postural sway is assessed during the motor-coordination tests using linear and angular perturbations of the platform (Sparto *et al.*, 2000).	Patient's scores are compared with age-related normative scores.
Calibration saccades	It was found that children under the age of 4 cannot maintain their gaze on a point source of light long enough for calibration procedures, and for these children illuminated toys or pictures are recommended (Cyr, 1980). In accordance with normal convention, a saccade to the right was represented by a vertical upward deflection and a saccade to the left by a vertical downward deflection (Snashall, 1983).	Calibration saccades of 30º were found to induce physiological end point nystagmus in several children. Despite encouragement, some children were unable to achieve calibration movements in one accurate saccade, and this may be due to inattention or to oculomotor apraxia due to immaturity of eye movement control (Snashall, 1983).
Post-head-shaking nystagmus	This test works best with visual fixation suppressed. This can be done with Frenzel lenses or barring that, in the dark with ophthalmoscopy to see the nystagmus once the head stops moving. Shake the patient's head side to side 30 times or more (Barton, 2000).	When the patient's head stops, his eyes should be stable. If there is an asymmetry in the vestibular input to the cerebellum, then one will see a nystagmus beating away from the detective side. Bilateral disease will not give an abnormal result.

Bárány rotation test	The chair rotation is adjusted by counterweight to deliver a maximum acceleration of approximately 40 degrees/s² and stop after 10 rotations with in 20 s (Kaga & Tsuzuku, 1992).	In children, the evaluation of post-rotary nystagmus is difficult, therefore per-rotatory is appraised.
Dix-Hallpike test	The child's head is in 30º of cervical extension and 45º of cervical rotation which serves to stimulate the posterior semicircular canals in the vertical plane. The Dix-Hallpike maneuver is initiated by having the child sit with legs straight out on the examining table with the head rotated 45º to one side. The child is brought quickly down over the edge of the table while extending the head 30º and maintaining the rotation (Whitney & Unico, 2001).	While the child is in the head-hanging position, the clinician observes his or her eyes for nystagmus. A Dix-Hallpike maneuver is positive if the child reports symptoms of spinning and rotational, up-beating nystagmus is observed with a latency of 5-15 s and duration of 30 seconds to 1 minute.
Pendulum tracking	Smooth pursuit tracking is usually achieved with a little practice to give a normal sinusoidal trace. Attention may wander away from the pendulum, but this is easily distinguished from ataxia in which small saccades are required in order to catch up with the moving target. It has been found that using a light source of variable intensity improves attention for pursuit movements in hyperactive children (Snasshall, 1983).	Spontaneous or positional nystagmus is observed.
Optokinetic test	The optokinetic stimulus could be a small, hand-held drum with narrow stripes, and this causes problems of both attention and irregularity of optokinetic nystagmus. As narrow stripes in the central field of vision induce pursuit optokinetic nystagmus, it would be much better if an involuntary optokinetic nystagmus to whole field stimulation is induced, as this is present from birth onwards and avoids the problems of contrast sensitivity and the lack of peripheral field stimulation (Snashall, 1983).	Spontaneous or positional nystagmus is observed.

Rotary chair test	To induce the VOR (Vestibular Occular Reflex), the individual is rotated either clockwise or counterclockwise in a mechanical chair in a dark room at a velocity of 60º / sec. Per-rotary responses are collected for 30 seconds or until the nystagmus stop. The chair is then stopped and post-rotary nystagmus is recorded for 30 seconds. The sequence of the trial could be as follows: First the head upright orientation is measured following clockwise rotation and then following counterclockwise rotation; second, the head down orientation following clockwise rotation and then following counterclockwise rotation. Participants are told verbally to put their "head down" immediately following cessation of chair rotation (Goldberg *et al*., 2003).	Spontaneous or positional nystagmus is observed
Rapid head movement test	Cohen and Kimball (2004) compared the results from groups given slow and rapid head movements to determine if the speed of head movements affects recovery as indicated by performance on the repetitive head movement test. In this test the patient sits in a standard chair, with a basket of small beanbags in front of his or her feet. The examiner stands 1 meter in front of the chair, holding an empty basket 100 cm above the floor. Moving as rapidly as possible, the subject moves the beanbags one at time to the examiner's basket, while the examiner times the task with a stopwatch.	The therapist then rates the intensity of vertigo elicited by the task, using the following scale: Ratings of vertigo intensity used a 10-point scale: 1 none, 2-3 slight, 4-5 mild, 5-7 moderate, 8-9 severe, and 10 extreme vertigo.
Head-thrust test	Ask the patient to keep his gaze on a distant point while one rapidly turns his head to one side and then the other. Be sure that the patient cannot predict when and by how much one will move his head (Barton, 2000).	Watch for a small saccade back to the target after the head turn has stopped.
Visual acuity during head motion	Ask the patient to read the eye chart at a distance while one rapidly oscillates his head (Barton, 2000).	The patient's visual acuity should not fall more than three to four lines from what it is with the head still with bilateral disease.

Tandem Romberg test	Standing heel-to-toe, with weight distributed equally on both feet and chin parallel to the floor and arms folded together against the chest. In the first trial, the subjects with eyes open performed the tandem Romberg on foam. In the second trial, the subjects with eyes closed performed the tandem Romberg on foam (Diamantopoulos *et al*., 2003; Johnson *et al*., 1998).	The test was declared successful (pass) when the subject managed to maintain the tandem Romberg posture for 1 min, a false start when balance was lost within the first 5 seconds of the test (with the test re-starting within the next minute) and unsuccessful (fail) when loss of balance occurred at any other time for the duration of the test. Loss of balance was recorded when one foot would move out of the heels-touching-toes configuration.

The following of these tests are recommended as tests that can be easily used by practitioners in practice, because no expensive or computerized methods are part of their methodology: The hand operated rotating chair, positional test, post-head shaking nystagmus, Dix-Hallpike test, pendulum tracking, rapid head movement test, head thrust test, visual acuity during head motion and the tandem Romberg test.

Recommended activities and treatment programmes

Murray *et al. (*2001) indicate that treatment intervention should be exercise oriented and individually designed toward attaining goals, including: improving sensory organisation and motor coordination to increase balance, decreasing positional and movement-related dizziness, improving visual-vestibular interactions and gaze stability during head movement, improving visual following when the head is stationary, improving level of activity and independence and decreasing risk of fall.

For better adaptation of the vestibular mechanism it is recommended that movement should be provided in all planes and in all directions (Williams, 2003). Williams (2003) indicates that the type of movement should be varied by using the following approaches: Maximize the visual, auditory and communication inputs and assess the child's preference for light or firm touch (if the child is deaf/blind use body and finger signs); supervise bathing, swimming, skating and trampolining, keep trainer wheels on bicycles until competence is achieved, wear goggles when swimming and be careful about diving and avoid surfing or other dangerous sporting pursuits. It is also recommended that some will have to wear helmets, knee and ankle pads, that handrails and smooth walking surfaces should be provided and that steps should be eliminated where possible. Over-arousal should also be minimized and inappropriate sensory experiences should be dampened.

Williams (2003) indicated that sensory integration of multiple systems will be improved by moving young babies slowly and securely from one position to the next and by stabilizing the torso in the chair or seat in order for the hands to be free for play and touch activities. The child should also be actively involved by pushing himself on equipment or telling the therapist when to stop or start a motion and activities should be selected that provide ocular input, for example, switching on the lights for a tunnel activity or attaching a torch to the scooter board. However, the stimulation should only be provided in the context of the child's developmental needs. Williams (2003) also indicates that proprioceptive input is enhanced through the use of weighted objects, firm pressure to joints, movements against gravity and traction or resistive activities.

Bouncing on Swiss balls or mini-trampolenes are advocated to build up the otolith-ocular reflex as well as otolith-postural reflexes and thereby contribute to otolithic recalibrations (Williams, 2003). The therapist can also use a variety of swings hung low to the ground to allow children with their fear of movement and car sickness to receive vestibular or movement input in a linear and non-threatening manner. Climbing structures and jumping activities will also help to give them more information about their bodies and head position in space (Williams, 2003).

In general, activities should involve using the eyes while the head and body are in motion (Hain, 2003). Although many advocated activities like golf, bowling, tennis, racquetball and ping-pong require this, Hain indicates that the key is to find activities that are fun, safe, and somewhat stimulating. Just walking around the block, looking from side to side may be a useful activity, while dancing is also indicated to be an excellent vestibular rehabilitative activity.

Alternative balance activities, yoga, tai chi and martial arts are also activities that have been considered in the literature for use in vestibular rehabilitation (Hain, 2003). Tai chi and yoga both incorporate some relaxation which may be helpful for those who have anxiety accompanying their dizziness or imbalance. Although doing such activities is intrinsically lower in cost than individualized therapy, their efficacy has not been compared by means of research to individualized therapy. However, they are probably most appropriate for those who have "graduated" from individual physical therapy (Hain, 2003).

Gaze stabilization exercises are indicated to be exercises which are especially appropriate for persons with bilateral vestibular loss, as well as being a reasonable procedure for persons with unilateral vestibular disturbance such as vestibular neuritis or persons who have had tumors of the 8th nerve removed (Hain, 2003). These exercises should be "progressed" to more difficult ones as they are mastered. From the literature, virtual reality training (Viire & Sitarz, 2002) also seems like a particularly promising method of treating people with inappropriate visual dependence. Persons with visual dependence are the people who get sick from looking at ceiling fans, or going to the omnimax. Virtual reality is new and at present, there are only a few studies that bear on this intervention. However, some preliminary work has been done by Viire (2002), suggesting that virtual reality may help assist in increasing abnormally low vestibular ocular reflex gain.

Many clinicians who do vestibular rehabilitation believe that for treatment to be effective, the client must move the head rapidly enough to elicit vertigo. A programme based on repetitive head movement tasks was applied to fifty-three patients with chronic vertigo caused by peripheral vestibular weakness (Cohen & Kimball, 2004). The success of the programme was measured by means of the time to perform a repetitive head movement task and intensity of vertigo elicited by that task, questionnaires about independence in activities of daily living and reported usual intensity of vertigo. It was concluded that vertigo decreased and speed of head movement improved after the programme of vestibular rehabilitation was followed, regardless of speed of treatment exercises. It was concluded by Cohen and Kimball (2004) that a simple purposeful activity can be useful to evaluate improvements after vestibular rehabilitation.

Cohen and Kimball (2004) showed that performance on the repetitive head movement task is impaired compared to normal. In other words, people with vestibular impairments perform the task more slowly than normal people, and the beanbag task elicits vertigo in patients with peripheral vestibular disorders. Cohen *et al*. (2004) also replicated the finding that the repetitive head movement task elicits vertigo in individuals who have been diagnosed with vestibular impairments. This study also shows that performance improves after vestibular rehabilitation as patients performed the repetitive head movement task more quickly and showed reduced vertigo intensity (Cohen & Kimball, 2004).

Levinson's research (1994) on dyslexia cites that motion related exercises, motor related exercises, and (vision) eye-hand coordination exercises that stimulate the inner ear (cerebellar-vestibular system), result in academic improvement for dyslexics.

In a home based programme based on repetitive head movement tasks, children with chronic vertigo (Cohen *et al*., 2004) had to move their heads rapidly in all planes in space. In Exercise 1, subjects nod up and down (“yes”), while in Exercise 2 they had to roll the head side to side (i.e. right ear toward right shoulder and then left ear toward left shoulder). In Exercise 3, subjects shake their heads back and forth (“no”) and in Exercise 4, they had to make circular head motions, clockwise, a brief rest and then counterclockwise. In Exercises 5-7, subjects repeat Exercises 1-3 while standing and incorporating trunk rotations. Participants were instructed to move their heads rapidly enough to elicit mild vertigo. These home programme exercises had to be done five times per day: before breakfast, before lunch, mid-afternoon, before dinner and before going to bed (Cohen *et al*., 2004).

To help children with Asperger’s Syndrome with their fear of movement and carsickness, Delaney (2002) indicated that one can use a variety of swings hung low to the ground to allow them to receive vestibular or movement input in a linear and non-threatening manner and climbing structures and jumping activities to help give them more information about their bodies and head position in space.

According to Belgau (2003), sensory integration activities that require individuals to balance precisely, make spatial judgments and provide a means of allowing feedback are the most powerful and effective activities available for maintaining and improving brain-processing efficiency and allowing an individual to become an efficient learner and improve academic success. The Learning Breakthrough Program was developed for this purpose (Belgau, 2003). According to Reynolds *et al.* (2003), the DDAT (Dyslexia, Dyspraxia and Attention Disorder) exercise treatment programme is an extensive and adaptive course mapped out over many months. It is a complex programme of integrated sensory stimulation, incorporating visuo-motor and vestibular therapy which has been uniquely structured in the combinations and weightings of the sensory inputs. Key elements of this program include the use of a balance board, throwing and catching of bean bags (including throwing from hand to hand with careful tracking by eye), practice of dual tasking and a range of stretching and coordination exercises. Research indicated that this exercise based treatment had a direct beneficial effect on balance, dexterity and eye movement control and was also effective in improving cerebellar function and in the controversial role to improve cognitive skills and the performance of literacy.

It is indicated that a high percentage of children with dyslexia, dispraxia or attention deficit will show cerebellar or vestibular problems. In this regard, Posturography and ENG (Electronystagmography) tests revealed that remediation of **c**erebellar/vestibular signs by means of the DDAT exercise programme will, if followed for an appropriate period, lead to effective remediation of the cerebellar/vestibular skills. In addition to the specific cerebellar/vestibular learning indicated, the training will also transfer to cognitive skills such as phonology, working memory and speed of processing that form the fundamental basis of cognitive functioning and underpin the subsequent development of literacy skills. In addition to the above near-transfer effects, the "accelerated" learning ability ensuing from treatment of the cerebellum will also lead to normal or above normal acquisition of literacy. There would presumably be a delay in this effect, with progress acceleration occurring primarily after the treatment of the cerebellum is complete. Progress should nonetheless occur without the need for further exercise treatment, assuming that normal reading support is available via the child's school (Cohen & Kimball, 2004).

Murray *et al*. (2001) indicate that assessment and treatment are significantly enhanced with the SMART Balance Master. This state-of-the-art equipment provides reliable assessment of balance functions, evaluating sensory parameters using a moving visual environment in conjunction with a moveable surface. After identifying under what sensory conditions the child may have problems and what movement strategies the child uses to maintain balance, a treatment program is developed. The SMART Balance Master provides quantative and objective data to support the evaluation and progress of therapy. This form of computerized dynamic posturography (CDP) incorporates a motorized force platform and visual surrounds, both of which can be sway-referenced so as to follow the subjects' center of gravity sway angle directly.

CONCLUSION

Blomgren (1989) stated that no matter what vestibular disfunctioning the child experiences, the toll taken on a child's emotional reserves and quality of life can be devastating. These vestibular disorders are exhausting and the child may feel worn down, frustrated, isolated, tense and somehow different. In addition, their self-esteem suffers and they have emotional problems. They feel guilty for being unable to control their feelings and behaviour. Helplessness to stop the symptoms, such as the floor tilting or the room spinning is often felt by them. Hence, when vestibular disorders aren't diagnosed and treated, the disorder will increase and sufferers may be robbed of self-esteem, control and hope (Blomgren, 1989).

This review article has confirmed that relationships between vestibular deficiencies and the motor development of children do exist, and especially between the vestibular system and dyslexia. Different tests evaluating vestibular loss were identified of which many can be used successfully in practice. Various successful rehabilitation programmes were also identified and discussed and which can be implemented in the improvement of children with vestibular deficiencies.

This literature review indicated many possibilities for future research. It is recommended that this should be aimed at exploring the relationship of different semicircular canals with different motor functions, the effect of different rehabilitation methods and activities on a specific semicircular canal, the effect of different rehabilitation programs on different vestibular deficiencies and which type of dyslexia will benefit mostly from vestibular rehabilitation.

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