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Abstract

Background: Descriptions of children with sensory dysfunction of the vestibular system are sparsely cited in the literature. Notable improvements in vestibular dysfunction have been seen in adults with physical therapy interventions. **Case Description**: The patient was a 2-year-old child with notable vestibular dysfunction, a history of recurrent ear infections and child neglect. Examination procedures were limited by lack of vestibular outcomes specifically in this young population. Interventions consisted of balance activities, improving tolerance to multidirectional perturbations and gross motor skills. **Outcomes**: Vestibular outcome measures were unable to be used due to the child's speech delay. Objective observations and tolerance to activities were used to determine improvements. **Discussion:** The purpose of this case study was to highlight the use of physical therapy interventions and the successful progress after 20 sessions in a pediatric patient with sensory dysfunction of the vestibular system. **Conclusion:** There are limited metrics of vestibular outcomes, particularly in this young population due to limited speech, thus assessments are limited to indirect measures of vestibular function (i.e. symptoms). Exercise interventions that focus on the enhancement of sensory integrative postural control abilities in children could be effective for the arrest of the progressive motor development delay with vestibular impairment.

Keywords: vestibular rehabilitation, vestibular dysfunction, balance, postural control, pediatrics, physical therapy

Introduction

The vestibular system is a complex sensory system that provides the leading contribution to the sense of balance and spatial orientation for the purpose of coordinating movement with balance.[9] Balance ability is determined by the integrity of three sensory systems (vision, somatosensation, and vestibular), the integration of this sensory input by central mechanisms and the integrity of the motor components of balance (e.g. muscle strength).[9] The primary job of the peripheral vestibular system is to detect head movement, head position and communicate information to the central nervous system.

The symptoms experienced by patients with vestibular dysfunction vary by nature of the dysfunction.[9] The dysfunction may be peripheral or central. Peripheral lesions may be unilateral or bilateral and can further be classified as a loss (i.e. areflexia), hypofunction, or irritative (e.g. benign paroxysmal positional vertigo [BPPV], Meniere's disease).[9] It is likely that the patient discussed in this case study was experiencing unilateral dysfunction of peripheral vestibular function based on the signs of severe vertigo and nystagmus he was experiencing.

Studies show that children with known vestibular dysfunction may have progressive developmental delays, inability to focus their eyes during movement, poor static and dynamic balance and symptoms of vertigo or feeling off-balance.[2] Evidence in the literature also shows that these children exhibit more postural control instabilities and slower gait speeds.[7] It has been well established that certain medical diagnosis such as cerebral palsy, Chiari malformation, attention-deficit hyperactivity disorder (ADHD), developmental coordination disorder (DCD), concussion and childhood cancer, tend to affect the peripheral vestibular system in infants and children.[2] For example, individual studies reported some form of vestibular dysfunction in 70% of children with severe to profound sensorineural hearing loss, 100% of children with meningitis, and 92% of children with congenital cytomegalovirus and hearing loss.[5] However, a recent epidemiological study showed that 5.3% of parents reported that their child had problems with dizziness or balance problems, with a slightly higher prevalence in females over males.[5] Of this 5.3%, only 29.9% of them receive treatment.[2] Prevalence increases with age from 4.1% in children between the ages of 3 and 5 years to 7.5% in children aged 15 to 17 years.[6] Therefore, vestibular dysfunction might be more widespread than previously thought, causing many children to experience poor balance, delayed gross motor skills, and poor gaze stability.[2] Children with vestibular dysfunction have also been shown to sit, walk, stand and hold their head at a later age compared with age-matched peers who do not have vestibular dysfunction.[5]

Children with loss of function or hypofunction of the vestibular apparatus since or shortly after birth present with a developmental delay that is progressive.[9] Young children are often unable to describe symptoms, but rather avoid activities or cry. Despite an increase in reports of vestibular dysfunction in children and the associated impairments, there are few studies of the epidemiology or rehabilitation for vestibular dysfunction in children. In the few studies that have been published, vestibular rehabilitation has focused training for use of remaining vestibular function to improve balance. In order to develop appropriate interventions, physical therapists must understand factors that affect behaviors, symptoms and determine which factors are intact and functioning properly.[9] The Committee for the Classification of Vestibular Disorders of the Barany Society identifies categories for the classification of vestibular symptoms: vertigo, dizziness, vestibulovisual, and postural.[9] Internal vertigo is the sensation of self-motion when no such motion is occurring. It may be spontaneous or triggered via position, head motion, visual or sound induced.[9] Vertigo can often be due to a vestibular problem for which vestibular

rehabilitation is appropriate.[9] In contrast, dizziness is the sensation of disturbed or altered spatial orientation without a sense of motion and may be spontaneous or triggered by factors similar to those that trigger vertigo. Vestibulovisual symptoms are typically the result of vestibular pathology or the interplay between visual and vestibular symptoms.[9] Clinically, this is often referred to as impaired gaze stabilization. Postural symptoms refer to symptoms of imbalance in upright postures. Vestibular related postural symptoms include leaning or tilt, holding onto an object or other person to walk or stand still, loss of balance and stumbling.[9]

To my knowledge, little research has been done regarding the effects of physical therapy interventions on young children with vestibular dysfunction without a neurological diagnosis. The purpose of this case study is to highlight the use of physical therapy interventions and the successful outcome in a pediatric patient with sensory dysfunction of the vestibular system after 22 weeks.

Case Description

History

The patient was a 2-year-old male referred to physical therapy for concerns regarding overall delayed development secondary to a complex medical history. He lives with a foster parent as the biological parents' rights had been terminated at the patients "well child" visit months prior due to neglect. The foster mom also reported primary concerns related to limited speech-language development and an increase in red flags for sensory processing disorder. The patient is also followed by multiple specialties including neonatology, ear, nose and throat specialist, pediatric pulmonology and pediatric ophthalmology.

The patient has a longstanding past medical history following his premature birth via emergency C-section at 26 weeks, weighing 2 lbs, 3 oz. He has a history of apnea, oxygen use, dissociated nystagmus, multiple developmental delays, history of intraventricular hemorrhage, ear tubes placed due to recurrent ear infections and plagiocephaly of the right posterior head. Reported delays in milestones include: rolling at 6 months, crawling at 9-10 months, and walking at 18 months. A verbal consent was given by the foster mother prior to starting this case study.

Examination and Evaluation

The patient was evaluated by a physical therapist. Due to developmental delays in speech and comprehension, a standardized outcome measure such as the Peabody Developmental Motor Scales (PDMS) was not initiated at the initial evaluation. Instead, the child was observed in an arena style environment with physical therapy, occupational therapy and speech therapy all observing. Quantitative vestibular function testing was not done in this specific evaluation.

The physical therapist first evaluated vision and hearing within their scope of practice and gathered relevant past medical information. The patient had a history of premature eye development followed by pediatric ophthalmology. Abnormal visuomotor tracking and concurrent oscillations of the head with active tracking were noted, seemingly related to abnormal vestibular processing. The patient had a longstanding history of recurrent ear infections and was at risk for hearing loss due to consistently failing screening measures in one ear. However, he had tubes placed the previous year and passed a full hearing screening for the first time 3 months later.

The patient also demonstrated sensory processing concerns. The patients frequent head nodding may relate to sensory delays with his vestibular system as he seeks vestibular input for balance and regulation, especially considering his history of recurrent ear infections. The patient's foster mom reports he is easily agitated and becomes frustrated due to communication breakdowns. The patient does not tolerate input and perturbations in a medial-lateral plane but does in an anterior-posterior plane. When medial-lateral perturbations are introduced, patient appears to become dizzy (e.g. wanting to sit on the ground, crying, closing eyes, throwing head back). With increased spinning or lateral input to the vestibular system the patient also performs the following actions: closing eyes, sits down, lateral trunk lean, sticks fingers in ears (both ears or right ear only).

Gross motor skills were evaluated due to the primary concern of delayed development. The patient demonstrates toe walking at about 5-10° of plantarflexion, consistent with the point of spasticity "catch" with rapid heel cord stretch. He is unable to initiate jumping, maintain single leg stance or tandem stance and requires two hand-held assist when ascending/descending stairs. The patient prefers to creep up/down stairs rather than walk. As stated above, the patient was also delayed in meeting major developmental motor milestones such as rolling, crawling and walking.

As stated previously, the gross motor skills were unable to be assessed through the PDMS at the initial evaluation due to lack of understanding and comprehension. The PDMS was later administered at the patient's 20th visit as described in the 'Treatment Interventions' section below.

Diagnosis and Prognosis

Upon completion of the evaluation, the physical therapist concluded that the patient may have an undiagnosed sensory dysfunction of the vestibular system based on patient's past medical history, objective observations, delayed development and intolerance to medial/lateral perturbations. This vestibular dysfunction could be contributing to the patient's developmental gross motor delays. The associated vestibular dysfunction could be a result of multiple factors in the patient's past medical history including recurrent ear infections and neglect. The patient demonstrates the following signs consistent with vestibular dysfunction as stated by Christy et al.:

- Developmental delays
- Poor static and dynamic balance
- Vertigo
- Inability to focus eyes during movement
- Intolerance to medial-lateral perturbations

Due to limitations in the physical therapist's scope of practice, a specific medical diagnosis could not be reached. However, several physical therapy diagnoses were made which include: lack of coordination, delayed milestones in childhood, generalized muscle weakness, retinopathy of prematurity (right eye), unspecified nystagmus, disorders of psychological development and preterm newborn.

Physical Therapy Goals

Short- and long-term goals were developed for the patient based on family goals, gross motor skills and signs of vestibular dysfunction observed in the initial evaluation. The outcomes for this patient are based on improved tolerance to varying types of vestibular input and the following goals:

- The patient will transition from floor to stand through right or left ½ kneeling independently and efficiently without using upper extremities for support.
    - Baseline: Patients primary mode of transition from floor to stand is through plantigrade.
- The patient will demonstrate the ability to stand on one foot without support for 1-2 seconds with adequate postural stability.
    - Baseline: Unable to perform
- The patient will ascend/descend 4 stairs with/without one upper extremity on rail, with one hand-held assist to increase independence with functional mobility.
    - Baseline: Creeps up/down stairs independently. Can ascend stairs with 2 hand-held assist
- The patient will initiate jumping with 2 footed take-off and landing.
    - Baseline: Unable to coordinate or attempt to jump
- The patient will stand on airex for at least 60 seconds x 2 with stand by assist in order to improve functional balance for mobility and age-appropriate play as well as improve vestibular tolerance.
    - Baseline: Able to maintain stance on airex for 10-15 seconds
- The patient will safely and independently navigate natural community environments and participate in age-appropriate recreational and fitness activities with peers.

Interventions

Rehabilitation for unilateral peripheral dysfunction focuses on reduction of vertigo and improvements in gaze and balance abilities.[9] Studies that have been conducted on children with vestibular dysfunction are focused on the impairment of the dysfunction related to balance, postural control and motor development. Unlike adults, who readily use vision and somatosensation to substitute for loss of vestibular function, the function effectiveness of these two sensations for balance is not fully developed in children.[9]

The challenge in vestibular therapy for children is to make the exercises interesting and fun for the child.[10] The exercises must be challenging and need to be modified over time to enhance recovery.[10] Equipment such as balls, toys and flashing lights, balance boards, trampolines and bubbles were used throughout treatment sessions.

Rehabilitation for vestibular-related impairments is based on several mechanisms based on the nature of the vestibular dysfunction.[9] The mechanism that was focused on specifically for this patient was habituation. Habituation is a central process of learning that is most commonly utilized when patients have problems with motion sensitivity.[11] It refers to the reduction of a response by repeated exposure to a provocative stimulus. The primary goal is to reduce vertigo and dizziness symptoms. Exercises to achieve habituation are selected on the basis of the specific movements or situations that cause the symptoms for the specific patient.[9]

Due to the child's young age and lack of understanding, vestibular interventions were greatly focused on balance and postural control rather than specific gaze stability exercises. Gross motor skills were addressed throughout the sessions as well. The patient was seen once weekly at the clinic for 45-minute sessions over 22 weeks and continues to be seen currently. Interventions were slowly advanced over multiple months as the patient's tolerance improved, therefore interventions are not divided up into

individual treatment sessions due to the longevity of treatment. The interventions are instead described as the complexity of the tasks progress. Table 1 provides a summary of interventions utilized in this specific case.

Treatment Interventions

Treatment began by focusing more so on how the patient's vestibular system reacted to several different types of input. Habituation interventions were initiated to reduce symptoms based on repeated exposure to provocative situations. Due to severe signs of dizziness and intolerance, interventions began in a seated position and progressed as appropriate. Surfaces were also progressed as the patient demonstrated improved tolerance. To begin, the patient was seated on a balance board with air-filled domes placed under the edges of the board to limit perturbations. The patient sits for approximately five minutes in each direction: medial-lateral and anterior-posterior. Initially the patient is very anxious but relaxes with increased time and is able to reach across midline. The patient is also able to visually track an object laterally, superiorly/inferiorly and diagonally while sitting on the balance board. The PT applies ¼ pound weights to all extremities in attempt to increase proprioceptive feedback.

Table 1: Summary of treatment interventions utilized

Treatment Interventions
Small ankle weights applied to extremities in order to increase proprioceptive feedback
Seated on progressively more unstable surfaces
Reaching for objects while sitting on unstable surfaces
Standing on progressively unstable surfaces
Reaching for objects while standing on unstable surfaces
Seated on a spinning surface
Sitting on trampoline with and without support
Ambulating across progressively more unstable surfaces
Initiation of gross motor skills (stairs, kicking, ½ kneel transitions)

As a progression, the patient was able to sit on the balance board without support from air-filled domes. Removal of the air-filled domes allowed for increased perturbations in medial-lateral or anterior-posterior directions. Initially, the patient preferred to sit on the board with his feet touching the ground to decrease the perturbations. After several minutes, the minute was able to tolerate tailor sitting with standby assist. The patient was able to visually track objects and reach across midline as he did in the prior sessions, but while tolerating more intense perturbations. Occasional losses of balance were experienced, however the patient was able to self-correct these rather than lean into the PT for support. The patient refused to stand on the balance board when initially attempted.

The patient's tolerance begins to improve after approximately 1 ½ months, and standing is attempted on the balance board with medial-lateral perturbations. He is able to maintain stance for 5 minutes total with 1-2 upper extremity support on a low mat table. The patient is also able to step on and off of the board with one hand-held assist multiple times.

The patient's postural control was assessed on another unstable surface (airex pad). In the first treatment session, the patient refused to tall kneel or stand on the airex pad becoming increasingly

irritated with each attempt. In the following sessions, the patient was able to maintain tall kneel on the airex pad for five minutes. This exercise was aimed at improving hip strength and challenging his postural control. Half kneeling was attempted, but the patient begins crying, closing his eyes and sits down. It appeared this position provided less stability and caused the patient to become dizzy as he was experiencing perturbations in multiple directions while trying to maintain his balance. Eventually the patient was able to stand for 60 seconds on the airex without upper extremity support while manipulating a toy, meeting the goal set by the PT.

A third surface that was used to challenge the patient's vestibular system was a trampoline. Initially the patient was seated on the therapist's lap while the therapist lightly bounced the trampoline creating perturbations. The patient progresses to sitting next to the therapist on the trampoline, but heavily leans into the therapist with perturbations. With attempts to remove support, the patient becomes increasingly upset crawling on the therapist's lap. After several treatments of incorporating the trampoline, the patient was eventually able to tolerate sitting on the trampoline alone with slight bouncing.

To further challenge the patient's vestibular system, we placed the patient on a swivel chair with contact guard for safety. Several slow spins were completed, one at a time, in each direction to challenge the vestibular system. Initially, the patient was only able to tolerate half of a full rotation in each direction before becoming upset (vocalizing, reaching for the therapist).

In future sessions, the child was spun in one complete rotation to the left on the swivel chair. When the chair is stopped, the patient was observed to be leaning to the left and puts his index finger in his right ear. With time provided between the next trail, one spin was completed again to the left with decreased lateral lean noted. When the chair was spun to the right, a lateral lean is present, but decreased compared to the left spin. In the future sessions, the PT was able to progress to 3-4 consecutive spins before the patient became dizzy and upset.

Moving surfaces, such as a gliding bolster swing, began to be incorporated with increased tolerance. Perturbations in the medial-lateral and anterior-posterior planes were tested at a slow swinging speed to increase the likelihood of tolerance. The patient is initially unable to tolerate this activity at all. Over time the patient is able to tolerate five minutes of swinging without signs of dizziness or becoming upset. The patient's vestibular system is also tested while sitting on a Rody (inflatable horse) with intermittent bouncing. The patient is initially able to tolerate this activity for approximately five seconds prior to becoming upset.

Activities from above were incorporated throughout treatment sessions in order to improve tolerance of the patient's vestibular system. Gross motor skills were also address intermittently throughout all sessions including: ambulating across various surfaces and over objects, stairs, jumping, running, ball skills, transitions, and functional balance.

The gross motor skills of the PDMS were tested at the patients 20th visit as he had made progress in speech and understanding. Based on the gross motor quotient of 74, the patient was 1.73 standard deviations below the mean compared to peers his age, suggesting he does have gross motor developmental delays. The scores are reflected in Table 2.

Table 2 - PDMS scores

	Standard Score	Percentile ranking (%)	Age Equivalent in Months
Stationary (raw score): 38	8	25	18
Locomotion (raw score): 87	4	2	17
Object Manipulation (raw score): 16	6	9	22

The PDMS has an excellent test-retest reliability of 0.97.[4] The validity scores are correlated with age (r = 0.80-0.93).[4] Another outcome measures that could have been used is the Pediatric Balance Scale (PBS). The test-retest reliability is shown to be excellent in school-age children with mild to moderate motor impairment (0.998).[3] However, a value is not found in the literature for children as young as 2 such as in this case study.

Outcomes

This is a case report of the child's initial progress, but due to the complex nature, the patient will continue to need additional weekly PT sessions. The patient's outcomes after 22 sessions are based on improved tolerance to varying positions on varying surfaces for increasing times and his progress made in gross motor skills. Table 3 outlines progressions that have been made over the first 22 weeks following initiation of PT.

In summary, the patient appeared to experience less dizziness, specifically when challenging the patient in a medial-lateral plane and multidirectional planes. The patient also performed less head shaking to equalize the vestibular system when challenged in these planes. Along with the improved tolerance to movement, the patient was also able to meet motor milestones and improve his gross motor skills.

Table 3 – Comparison of the patient's initial tolerance to perturbations and various surfaces and how the patient's tolerance progressed over 22 treatment sessions.

Initial Tolerance	Tolerance Progression
Seated on balance board for 15 seconds with air-filled domes under edges to minimize perturbations	Standing on balance board 2x1 minute with medial-lateral and anterior-posterior perturbations - intermittent 1-2 upper extremity support
Seated on airex pad with minimal/no perturbations	Standing on airex for 60 seconds without upper extremity support while manipulating a toy
Seated on swivel chair tolerating ½ of a full rotation in each direction with slow spins	Patient able to tolerate 3-4 full consecutive rotations on swivel chair prior to signs of dizziness

Unable to tolerate any time swinging on dynamic surface (gliding bolster swing)	Able to tolerate up to 5 minutes swinging on the gliding bolster swing with multidirectional perturbations
Crawling across unstable surfaces (mats, dynadisc, foam pads)	Ambulating across unstable surfaces with standby-assist, minimal hesitancy and minimal losses of balance

Discussion

There have been increasing reports of vestibular dysfunction in children and a very low percentage of them have been seeing any health professional for their symptoms, suggesting this is an overlooked entity.[9] Vestibular dysfunction can have a serious lifelong impact on the individual's performance and well-being thus future research is needed regarding vestibular rehabilitation in very young patients such as in this case report.[9]

Limited literature has been cited regarding vestibular hypofunction in children without neurological conditions.[2] However, Dr. Rine and colleagues first determined that vestibular hypofunction in children without a neurological diagnosis caused progressive delay of gross motor abilities and abnormal development of the postural control system.[8] Functional impairments were measured by using the Peabody Developmental Motor Scales (PDMS), Sensory Organization Test (SOT) and a modification of the Motor Control Test (MCT) with electromyography. The PDMS showed a progressive developmental delay, indicating that children with hypofunction do not "catch up" on their own.[8] The SOT showed that children with hypofunction, regardless of age, not only had poor use of the vestibular system but also the visual and somatosensory system for postural control, suggesting an interdependence on the three sensory systems for balance.[8] The MCT with electromyography showed that children with hypofunction had delayed activation of the tibialis anterior and stepped or fell, hypothesized to be due to poor vestibulospinal responses.[8] To address vestibular hypofunction with physical therapy interventions, Rine and colleagues focused exercises on improving static and dynamic balance, gaze stability, gross motor skills and coordination.

Initial interventions in this case study were aimed at finding surfaces and directional perturbations that disturbed the patient's vestibular system. Treatment addressed static and dynamic balance, postural stability, gross motor skills and coordination. Due to the young age of the patient, gaze stability exercises were not addressed specifically.

Vestibular dysfunction in adults has been widely cited in the literature but has been scarcely cited on the pediatric side. Research in adults simply cannot be translated to pediatrics. There are a multitude of outcome measures or special tests that have been published by the American Physical Therapy Association (APTA) to assess vestibular dysfunction in adults such as rotary chair testing, head impulse test (HIT), vestibular ocular reflex (VOR), dynamic visual acuity, head thrust, etc.[1] Adults are able to understand directions given in these tests and keep their attention on the task, unlike children. There are limited metrics of vestibular outcomes, particularly in this young population due to limited speech, thus assessments are limited to indirect measures of vestibular function (i.e. symptoms).

According to Janky et al. quantitative tests of vestibular function can be performed in the pediatric population based on age. For vestibular function tests, children aged 0 to 2 years typically received

rotary chair, cervical vestibular evoked myogenic potential (VEMP), and video head impulse test (vHIT).[5] Vestibular function testing can be difficult in children for a variety of reasons. Children may not be able to self-report or even be aware that the symptoms they are experiencing are abnormal.[5] Children also tend to have short attention spans making testing difficult.[5]

If the child were older, gaze stability exercises could have been used to make more rapid progress. The vestibular ocular reflex (VOR) is a common gaze stability adaptation exercise aimed at diminishing symptoms and improving gaze stability and balance ability.[9] The head is moved in a yaw (side to side) and pitch (up and down) motion while keeping gaze fixed on a stationary object.[9]

Conclusion

The purpose of this case study was to highlight the use of physical therapy interventions and the successful progress after 22 sessions in a pediatric patient with sensory dysfunction of the vestibular system. Exercise interventions that focus on the enhancement of sensory integrative postural control abilities are effective for the arrest of the progressive motor development delay in children with vestibular impairment.[8] Rine et al. interventions included four categories: eye hand coordination, general coordination activities, visual motor training, and balance training emphasizing visual and somatosensory awareness. Three of four of these categories were used in this specific case study, thus showing that children with vestibular dysfunction can improve with physical therapy interventions.

Furthermore, this case study supports the use of habituation in reducing vestibular responses through the use of repeated exposure to a provocative stimulus. Due to the child's young age, this was the most practical method to reduce the patient's symptoms. The method of habituation allows the physical therapist to keep the child engaged and participating with fun activities, while also addressing the root cause of their delayed motor development.

Future research could observe the time required for children to improve their motor skills, the best time duration of sessions, weekly frequency and the characteristics or nature of exercises that produce the best results in children. Another area that research could focus on are specific outcome measures for young children. There are limited metrics of vestibular outcomes, particularly in this young population due to limited speech, thus assessments are limited to indirect measures of vestibular function (i.e. symptoms).

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