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Neurological and Vestibular evaluation of dizzy children

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Abstract: Dizziness is a general nonspecific term used to describe many different sensations, including unsteadiness, imbalance, clumsiness, lightheadedness and vertigo. Dizziness is not an uncommon complaint in children with prevalence that ranges from 0.45 to 15%. Childhood vestibular deficits may present as visual disturbance, headache, unsteady gait, motor delay or learning disability and may result in delayed postural control, episodic vertigo, lack of coordination, and the development of paroxysmal head tilt in young children. Evaluation of patients presenting with dizziness begins with a detailed history, neurological examination, audio-vestibular and radiologic testing which are important in establishing a definitive diagnosis. During a detailed neurologic evaluation, the physician must examine the head, face, spine and extremities for abnormalities, malformations and dysmorphic appearances and assess the mental status, the integrity of the cranial nerves, the motor system, the reflexes, the sensory system as well as the coordination and gait of the patient. Findings suggestive of a central cause of dizziness should consider Magnetic Resonance Imaging (MRI) or Computed Tomographic (CT). Surface electroencephalography (EEG) is a useful electrophysiological investigation for evaluating a paroxysmal event in children. Also, for assessment of vestibular system function, there are several tests but VNG play a major role in diagnosis of dizziness. A dizzy child questionnaire was developed in the light of a good knowledge of causes of childhood dizziness and with the help of previously validated questionnaires which was filled through an interview with all parents of dizzy children as well as the children themselves whenever possible.

Keywords: Neurological . Vestibular . evaluation. dizzy children

Introduction: Dizziness is a general nonspecific term used to describe many different sensations, including unsteadiness, imbalance, clumsiness, lightheadedness and vertigo. Vertigo is defined as an illusion of motion of the patient's environment which suggests mainly disturbance of the vestibular system **(1).**

The main epidemiological studies reveal a prevalence of dizziness during childhood from 0.45 to 15%. It is sometimes difficult to make the correct diagnosis because children find it hard to describe the attacks, how long they last and what provokes or accompanies them

which could be a cause of the relatively low prevalence rates of dizziness throughout childhood **so** identification of pediatric vestibular dysfunction requires coordinating descriptions offered by the child, symptoms reported from parents, and clinical explanations by professionals **(1)**.

Childhood vestibular deficits may present as visual disturbance, headache, unsteady gait, motor delay or learning disability and may result in delayed postural control, episodic vertigo, lack of coordination, and the development of paroxysmal head tilt in young children. Children with a congenital or compensated vestibular dysfunction may present without symptoms **so** it's important to be recognized early as delay in treatment can affect other aspects of development such as spoken and written language, psychological state, and school performance **(2).**

Evaluation of patients presenting with dizziness begins with a detailed history, physical examination, audio-vestibular and radiologic testing which may be important in establishing a definitive diagnosis. The first objective is to determine if the dizziness is from a peripheral or central causes **(3).** The history should be identified in chronological order: the onset of the symptoms and description of their frequency, severity, duration, effect on the child, associated symptoms such as hearing loss, aggravating factors, whether they are progressive, static, or improving and other medical conditions such as medications or history of migraines. **(4).**

Neurological and Vestibular evaluation of dizzy children

Neurological evaluation:

A) Neurological examination:

During a detailed neurologic evaluation, the physician must examine the head, face, spine and extremities for abnormalities, malformations and dysmorphic appearances and assess the mental status, the integrity of the cranial nerves, the motor system, the reflexes, the sensory system as well as the coordination and gait of the patient **(5).**

Cranial nerve examination:

A thorough cranial nerve examination is indicated in all dizzy patients involving all cranial nerves which starts with examination of olfactory nerve and ends with examination of hypoglossal nerve. The following are the most important cranial nerves to be examined in children complaining of dizziness **(3).**

- 2^{nd} cranial nerve (Optic Nerve):

Optic nerve can be tested by visual acuity, visual fields, fundoscopy and pupillary light response. Visual acuity is assessed by standard charts which may display pictures instead of letters to evaluate visual acuity in young children. Each eye should be tested separately. Visual fields can be tested by bringing an object into the visual field from behind while the child focuses on another object directly in front of him/her. Funduscopic examination is vital for the assessment of optic disk and retina **(5).**

- 3^{rd}, 4^{th} and 6^{th} cranial nerve (Oculomotor, Trochlear and Abducent Nerves):

The extraocular muscles are innervated by these three cranial nerves. The oculomotor nerve innervates the superior, inferior, and medial rectus and the inferior oblique and the levator palpebrae superiosus muscle. The trochlear nerve innervates the superior oblique muscle. The abducent nerve supplies the lateral rectus muscle. In a cooperative child, a red glass is held over one eye, and the patient is asked to follow a bright white light. The child sees only one white/red light in the direction of normal function but notes a separation of the red and white images that is greatest in the plane of the affected muscle **(6).**

- 8th cranial nerve (Vestibulo-Cochlear Nerve):

Screening for hearing loss is an important component of the neurological examination because discovery of a hearing loss during the first 3 months of age is associated with a better prognosis with appropriate therapy. **(6).** Vestibular function in infants can be determined by searching for induced rotational nystagmus. Holding the infant in the outstretched arms of the examiner, who slowly turns his arms clockwise, leads to deviation of the infant's eyes in the direction of rotation, being associated with phasic nystagmus to the opposite side. The same phenomenon can be observed when turning counterclockwise, and there should be no post-rotational nystagmus when the examiner stops turning. Vestibular function can also be tested by caloric stimulation test **(4).**

Motor system examination:

Examination of the motor system help to locate the site of the lesion that may exist in the cerebral cortex, thalamic nuclei, brainstem, cerebellum, medulla, spinal cord, peripheral nerves, myoneural junction, or the muscle. The components of examination include muscle tone, power and deep tendon reflexes. Muscle tone is the unconscious, continuous, low-level contraction of muscles that creates the resistance to passive movement of a joint **(5).**

Starting from the age of 3 years, the normal child will squeeze the examiner's fingers on command, flex and extend the wrist and elbows, and abduct and adduct the shoulder muscles against resistance. The same holds for the lower extremities. Hip girdle muscle power may be assessed by observing the child climb stairs or get up from a sitting or lying position **(6).**

Deep tendon reflexes can be tested in all age groups. The most common tested reflexes are the biceps, triceps, brachioradialis, patellar, and Achilles reflexes. Hyporeflexia generally occurs in cases of lower motor neuron or cerebellar dysfunction, while hyperreflexia reflects upper motor neuron lesion. The plantar extensor response or Babinski sign, compromises extension of the hallux with fanning of the remaining toes. It is elicited by stimulating the sole of the foot with a blunt object beginning at the heel and extending to the base of the toes. A positive Babinski sign indicates upper motor neuron lesion but is normal below 18 months of age. An asymmetric plantar extensor response must always be considered as an abnormal sign **(5).**

Sensory system examination:

The evaluation of the sensory system is often difficult in infants and young children. Normally, infants and young children respond to touch stimulation by crying, withdrawing the extremity or by another alerting response. In older children, they will look directly at the

stimulated area and a cooperative child may accurately point to the area of stimulation. The physician should evaluate the senses of light touch, pain, temperature, vibration, and joint position (proprioception). The sense of light touch can be tested by having the patient has his/her eyes closed and The physician should touch patient's extremities and then ask him/her where he/she feels the touch. The sense of pain/temperature can be tested following the same process while using a pin or a cold fork. Vibration sense can be tested by applying a tuning fork over patients thumbs and toes and asking him/her if the vibration is felt. Proprioception is tested by moving the thumps and toes of the patient slightly up and down while his/her eyes are closed and ask him/her to identify the direction of movement **(5).**

Coordination:

Coordination is largely controlled by cerebellum. Cerebellar testing is important to perform in all patients with dizziness to better assess possible central causes. Examination may involve but is not limited to finger-nose-finger testing, heel-to-toe testing and rapid alternating movements. Cerebellar disorders typically manifest with ataxia which refers to a disturbance in the smooth performance of voluntary motor acts. Ataxia may also be demonstrated observing the child at play or reaching for an object. Sensory ataxia is found with diseases of the spinal cord and peripheral nerves. Sensory ataxia may be differentiated from cerebellar ataxia by the Romberg sign. A positive test consists of unsteadiness with eyes closed but attainment of normal balance with the eyes open in a patient with sensory ataxia **(3).**

Gait:

The gait examination is a cardinal feature of the neurologic evaluation and is best performed by observing the patient walk. For more accurate observation the patient must be barefoot and wearing minimum clothing. Toddlers, normally, walk with a wide base but the base of the gait narrows with age. A cooperative child older than 6 years of age, should be asked to perform tandem gait (the toes of the back foot touch the heel of the front foot). There are six basic pathological gaits in children which are hemiplegic, spastic diplegic, myopathic, neuropathic, ataxic gait, and chorea. Hemiplegic gait is characterized by walking with the toes in the affected foot striking the ground first, instead of the heel, which strikes first in normal children. This is associated with a unilateral decrease in arm swing, with the elbow and wrist often kept in a flexed position. The affected leg usually moves in a circular swing movement (circumduction). Spastic gait is characterized by stiffness, tip toe walking, and stumbling. Ataxic gait is wide based with irregular lurching steps and truncal instability, which result in lateral veering or even falling, when severe **(4).**

B) Neurological investigations:

Findings suggestive of a central cause of dizziness should consider Magnetic Resonance Imaging (MRI) or Computed Tomographic (CT) scanning especially in acute sustained vertigo which should be performed urgently to rule out a vascular event in patients who have

headache, vascular risk factors, or an examination that is not completely typical of a peripheral vestibulopathy **(7).**

A temporal bone computed tomography (CT) scan is the most appropriate imaging modality when certain peripheral processes are suspected owing to its high-resolution allowing visualization of the fine anatomic structures of the middle and inner ear. A non-contrast head CT scan may be beneficial in the initial workup of central causes of dizziness and vertigo, especially to rule out urgent causes such as hemorrhage, infarct and herniation. A contrast-enhanced head CT scan may be useful if malignancy or infection is suspected **(8).**

Magnetic resonance imaging (MRI) is the preferred imaging for assessing vertigo in the pediatric age group. Clinicians should advice neuro-imaging studies for children with vertigo who have neurologic signs and symptoms, risk factors of cerebrovascular lesions or progressive unilateral sensorineural hearing loss tinnitus or history of head trauma **(9).**

Vertigo and dizziness in association with epilepsy have been recognized since ancient times. Although vertigo and dizziness in patients with epilepsy may be related to adverse effects of antiepileptic drugs or linked to a non-epileptic comorbid disease, vertigo and dizziness can occur at the onset of a seizure itself (i.e., presenting as an aura) or often be felt as a sole manifestation of epilepsy **(10).** Surface electroencephalography (EEG) is a useful electrophysiological investigation for evaluating a paroxysmal event in children. It measures the electro potential difference between two points on the scalp. It is a non-invasive, readily available and inexpensive investigation that analyzes neuronal dysfunction and abnormal cortical excitability. EEG helps in differentiating epileptic from non-epileptic clinical event and focal seizures from generalized seizure **(11).**

Vestibular evaluation:

The vestibular system is one of the first systems to be responsive in the early stages of human development. Neuronal connections between the labyrinths and the brainstem oculomotor nuclei occur between 12-24 weeks' gestation **(12).**

The inner ear contains several groups of sensory cells, divided into two main functions: hearing (cochlea) and balance (vestibular) receptors. All these cells have one common character: they have cilia that when exposed to inclinations, they change cell polarization and send electric signals to the adjacent nerve fibers. The vestibular receptors are located, for each side, in the ampullae of the three semicircular canals and the maculae of the utricle and the saccule**.** Sensory Hair cells of the vestibular system respond to endolymph flow within the canal duct and encode passive and active rotations of the body and head in space **(13).**

The vestibular system is highly integrated with the eyes and the proprioceptive system for the maintenance of the body equilibrium. Since the integration of the three systems occurs at the vestibular nuclei, it is reasonable to state that the vestibular system is the main organ related to equilibrium. Therefore, the clinical evaluation of the vestibular system is of absolute necessity in patients with symptoms of imbalance whether they have episodes of vertigo, instability, abnormal eye movements or even falls **(14).**

The VOR is a vestibular-mediated reflex that helps maintain a stable image on the retina which is a critical requirement of visual acuity for maintaining clear vision on target in presence of head motion. In response to high frequency head movement in one direction, the VOR generates compensatory eye movements that are usually equal in magnitude but opposite in direction to keep visual targets on the fovea of the retina. This reflex is generated and maintained primarily by the ten organs of the inner ears of balance: six semicircular canals (SCCs, three on each side) and four otolith organs (the left and right saccule and utricle). The SCCs encode neural firings that represent angular head acceleration, and the otolith organs encode for linear acceleration**.** Normal individuals can maintain a steady gaze but patients with deficient VOR cannot keep up with high-velocity head turns and generate "catch-up" saccades after head impulses toward the damaged side **(16**).

VOR movements are accomplished by fixing the eyes on an object and turning the head back and forth. While in motion, it can be observed that not only the targeted object is clear, but objects within the peripheral vision can also be distinguished. This, therefore, explains that the purpose of this system is to stabilize the visual field while the head is in motion. In order for stability to be achieved, three elements that make up this system need to work synchronously: the vestibular organs, a central processing mechanism, and the ocular muscles. The process begins within the inner ear where angular velocity and linear acceleration are perceived by the semicircular canals and the otoliths, respectively. This information is sent to the vestibular nucleus complex and the cerebellum, where the output is sent to and read by the ocular muscles **(17).**

Both visual and somatosensory systems can only process relatively slow body movements, and can be demonstrated with a low-pass transfer function, with a cutoff frequency of about 0.2 Hz. The vestibular hair cells respond to frequencies from 0 to 16 Hz, being predominantly active in the range of 0.1–10 Hz in which the otolith organs perceive low-frequency linear accelerations (translations and tilt) up to about 1 Hz, whereas the semicircular canals (semicircular canals) perceive angular velocity between 0.1 and 10 Hz **(17).**

Bedside clinical examination is vital for localizing and diagnosing the underlying causes of dizziness and becomes especially important when symptoms are unclear or do not fall into easily recognized diagnostic categories. A comprehensive examination is necessary including assessment of visual, vestibular, and ocular motor function as well as coordination, gait, and balance **(18)**.

There are several tests and trials used in assessment of the vestibular system function; their results allow for accurate diagnosis of the cause. VNG, play a major role in diagnosis of dizziness and help to differentiate the location of the lesion between the central and peripheral part of the vestibular system. The caloric tests can examine each labyrinth separately. The caloric stimulus is not physiological, its responses are mainly caused by thermally induced convection currents in the perilymph of the semicircular canals. Furthermore, they are limited to the study of the lateral semicircular canals and are related

to frequencies ranging from 0.003 to 0.05 Hz therefore; they do not examine the most important frequencies of vestibular function and real-life situations (**19**).

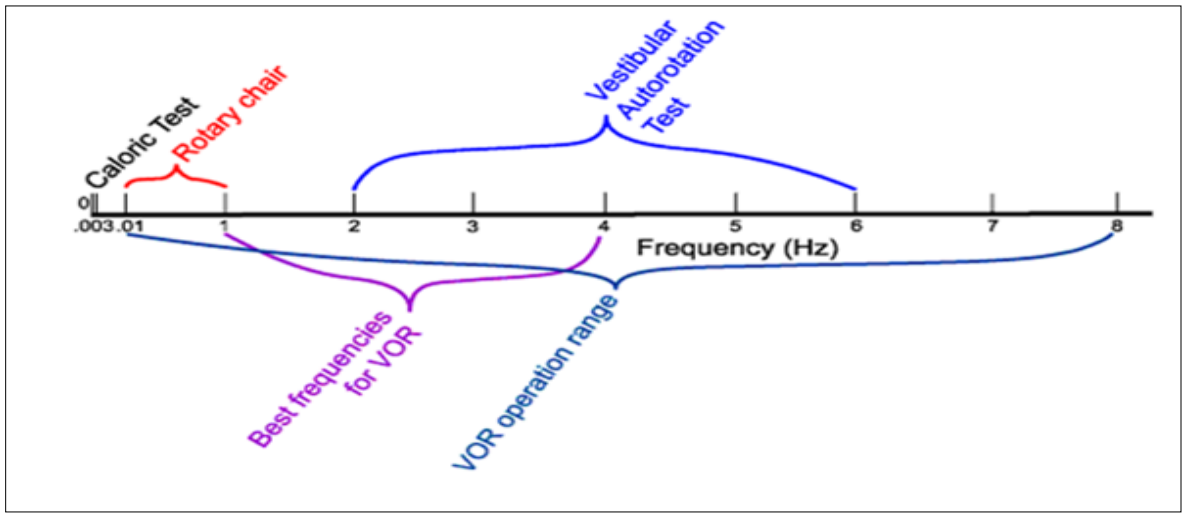

Figure (1): frequency range of vestibular system **(22)**

A dizzy child questionnaire was developed in the light of a good knowledge of causes of childhood dizziness and with the help of previously validated questionnaires: It included the following: (a) description of dizziness, (b) relevant medical history, (c) effect of dizziness on school, educational, and daily activities, (d) developmental and educational history, (e) past medical history, and (f) family history**.** It was filled through an interview with all parents of dizzy children as well as the children themselves whenever possible. **(27).**

Vestibular office tests

Vestibular office tests can be conducted using newly developed test materials for children. The tests included observation of spontaneous nystagmus, in which the child was asked to look ahead at the same time as he or she was engaged in a mental task. An alignment test was done by instructing the child to follow a simple small target (e.g., toy) in the frontal plane and the midsagittal plane and observation of full range of eye movement including the nine cardinal directions of gaze **(28).**

Oculomotor tests including Smooth pursuit test are done by observation of eye movements while moving toys in front of the child in horizontal and vertical directions and keeping the head fixed. Saccadic eye test was done by instructing the child to follow a little toy that appeared randomly behind a colored window. Gaze test was done by asking the child to focus on a small fixed toy at a central position, and then at 20 degrees to the right, left, up and down, at 20 cm distance, for about 30 seconds **(29)**.

Head thrust test was performed as a passive, fast and unpredictable single head rotation, 30 degrees off the midline, while the child's eyes focused on a small toy. The test results were considered positive if the eyes had to make corrective saccades to re-fixate onto the target**.** The head shake test involved either passive or active rotation of the child's head in the horizontal plane in a high frequency, low amplitude maneuver for 20 seconds with closed

eyes. The head was then brought to an abrupt stop and the eyes were opened and observed for nystagmus. The test results were considered abnormal if nystagmus was observed **(28).** Tests for posture and gait can be performed which included assessments of postural control during walking, and jumping on hard and soft ground, performed with eyes opened and closed if possible. Tandem gait test can be done in which the child walked blindly on a straight line to assess the general balance functions. Foam test is performed by asking the child to stand with both feet together on a foam mat covered with kids' games pictures with eyes open and then closed. Fukuda stepping test is performed by asking the child to march 50 steps in place with outstretched arms and the eyes closed and without moving. Deviation for more than 30° or moving forward or backwards (more than 50 cm) were considered a positive test result. Romberg's test can be performed by asking the child to stand on one leg. While, Sharpened Romberg test is performed by asking the child to stand with feet in heel-to-toe position with arms folded against chest, first with eyes open and then with eyes closed **(29)**.

Videonystagmography

VNG test battery:

(A) Oculo-motor tests:

Oculomotor contributions supporting VOR function can come from version and vergence eye movements which are simplified by the six extraocular muscles around each eye required for oculomotor function. These include saccades (rapid ballistic eye movements that allow one to change fixation from one target to another) and smooth pursuit eye movements (slow eye movements allowing one to track moving objects smoothly by focusing the image on the eye's fovea) **(32).**

1. Saccade test:

When a target is detected on the edge of the visual field. The oculomotor system can rapidly move the eyes conjugately and bring the image of interest onto the fovea. The saccade control system creates all voluntary and involuntary fast eye movements. The purpose of the saccade system is to be able to capture visual targets in the periphery of the visual field and focus them onto the fovea **(33).**

2. Smooth pursuit test:

Smooth Pursuit Eye Movements (SPEM) aim to hold the image of smoothly moving target on the fovea. SPEM represent a complex sensorimotor behavior integrating numerous perceptual, motor and cognitive processes including attention, prediction and inhibition **(Schröder., 2023).** SPEM are quantified by gain and symmetry. The gain (ratio of eye velocity to target velocity) in normal healthy individuals is usually >0.8 **(34)**.

3. Optokinetic test:

Optokinetic nystagmus (OPK) is a normal reflexive involuntary eye movement made in response to stimulus motion consists of slow-phase eye movement followed by a resetting fast-phase, bringing the eye back to its original position. OPK assists to reduce "retinal slip" by partially stabilizing the moving image on the retina. The strength of OPK is measured

using OPK gain which is the ratio of the velocity of the slow phase of OPK to the velocity of the stimulus **(36).**

4. Gaze evoked nystagmus:

The ability to maintain eccentric gaze is under control of the brainstem and midline cerebellum, particularly the vestibulo-cerebellum (especially the flocculonodular lobes). When these mechanisms fail to embrace the eye in the eccentric position, the eye drifts toward the midline (exponentially decreasing velocity), followed by refixation saccades toward the target. Such gaze-evoked nystagmus is central in origin and always beats in the direction of intended gaze **(33).**

(B) Spontaneous nystagmus:

Spontaneous nystagmus refers to involuntary rhythmic eye movements with alternating fast and slow components while eyes are in the primary position (i.e., fixed in the midline/central gaze) without provoking stimuli. Spontaneous nystagmus does not occur "spontaneously" but rather, most of the time, caused by an imbalance in the tonic vestibular inputs. To be valuable for clinical diagnosis, the characteristics of spontaneous nystagmus have to be recognized. An important feature of spontaneous nystagmus caused by peripheral vestibular pathology is that it is usually suppressed by visual fixation. If visual fixation fails to suppress spontaneous nystagmus or if direction changing spontaneous nystagmus in single head position is observed, then a lesion in the central vestibular system should be considered **(37).**

(C) Positioning Tests:

Positioning tests including the Dix-Hallpike test and the supine head-roll test are commonly used to diagnose posterior and lateral semicircular canal BPPV, respectively. The affected canal and pathology are detected according to the characteristics of the nystagmus provoked by the position change. By definition, the most prominent response for a given semicircular canal is provoked by an angular acceleration of the head in the plane of that semicircular canal. However, rotation of the head toward any semicircular canal plane evokes stimulation in all 6 semicircular canals to a degree **(38).**

Characteristics of classical positioning nystagmus include geotropic torsional direction, short-lived latency (5 to 20 seconds but some patients may have a delay of up to 30–45 s before onset), decay with repeated positioning, 30 seconds or less duration, and reversal upon rising. The nystagmus is accompanied by vertigo, which is often intense and follows the same time course as the nystagmus. The response usually fatigues upon repetition of the maneuver. The direction frequently reverses when the person sits up **(33).**

(D) Positional tests:

The purpose of the positional test is to determine if different head positions, not head movements, induce or change vestibular nystagmus. The more common positions include: sitting head turned right, sitting head turned left, supine head turned left, supine head turned right, right decubitus, left decubitus, and pre-irrigation position (head and shoulder elevated by 30 degrees up from the horizontal plane). Positional nystagmus is characteristically

classified by the direction of the fast component of the nystagmus but measured by the velocity of slow component **(33).**

(E) <u>Bithermal Caloric Testing:</u>

Bithermal caloric testing is the most commonly applied vestibular laboratory test. It is useful in assessing unilateral vestibular dysfunction. It uses a non-physiologic stimulus (water or air in the external auditory canal) to make a thermal gradient in the SCCs, thus causing convection currents that lead to endolymphatic flow and vestibular stimulation. The horizontal SCC develops the largest thermal gradient because of its close proximity to the external auditory canal, and the resulting convection current is increased by placing the patient in the supine position with the head tilted up 30 degrees, bringing the horizontal SCC in the horizontal plane. Because of the configuration of the horizontal SCC in this position, a warm caloric stimulus causes an excitatory response, producing nystagmus with a slow component directed away from the stimulated ear and a fast component toward the stimulated ear. A cold stimulus causes endolymphatic flow in the opposite direction, resulting in an inhibitory response and fast phases away from the stimulated ear **(39).**

Cervical Vestibular Evoked Myogenic Potentials (cVEMP)

They represent electromyographic potential in the muscles of the neck after intense acoustic stimulation. cVEMP response consists of initial biphasic positive negative wave (P13, N23) followed by a later biphasic negative positive wave (N34, P44). The cVEMP tracing consists of a positive peak P1 at about 13 ms, followed by a negative peak N1 at about 23 ms, which is called the saccular reflex that denotes the saccule's response to sound when using an air-conducted stimulus **(40).**

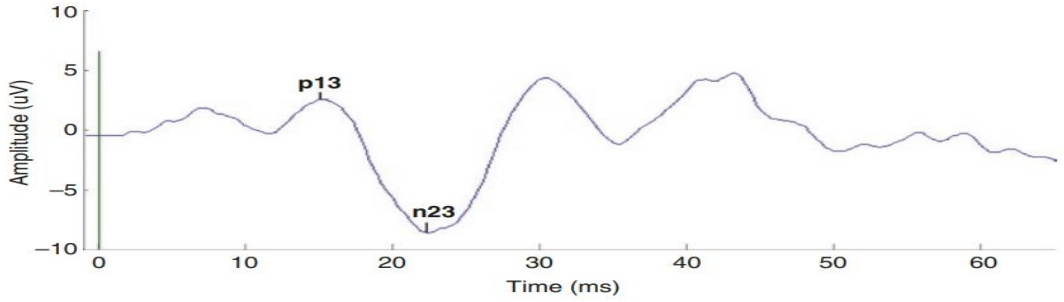

Figure (4): Waveform of cVEMP **(40).**

<u>Neural pathway of cVEMP:</u>

The physiology of cVEMP production has been hypothesized based on tendency of the animals to look in the direction of sound. Evolution has proved that vestibular system evolved earlier than the cochlear system. The saccule (one of the otolith organs) has remnants of hearing receptors **(40**). Once the saccule has been triggered by sound, neural firing happens through the afferent system along the vestibulocochlear cranial nerve **(40).**

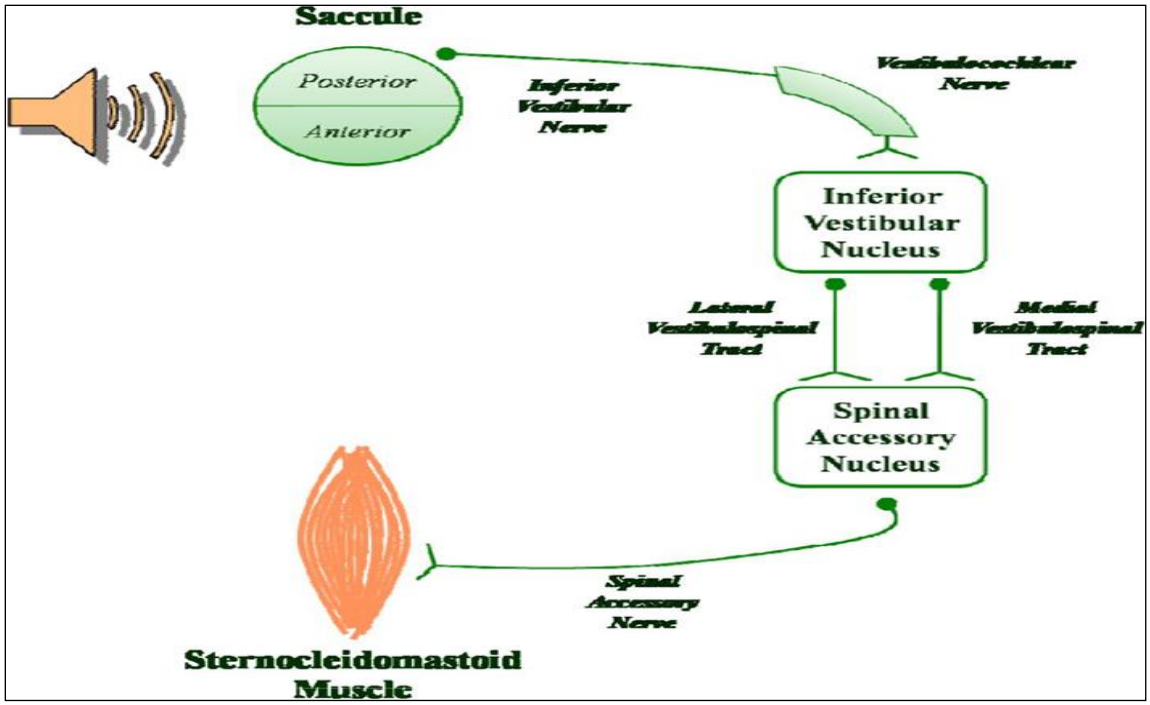

Figure (5): Diagram of the cVEMP neural pathway evoked by an air-conducted stimulus **(40).**

cVEMP responses to acoustic stimuli mainly reflect the function of saccule and inferior vestibular nerve. It is short-duration trans-mastoid direct current stimulation (**41).** Maintenance of tonic contraction of the sternocleidomastoid muscle during the test is a critical factor to produce cVEMP responses. If the muscle is not contracted adequately, the VEMP responses may be absent **(41).**

Electrode montage:

Surface electrodes were attached at the middle third of the sternocleidomastoid muscle (active electrodes), the sternoclavicular junction (reference electrode), and the center of the forehead (ground electrode). During the test, the electrode impedance was less than 5 kΩ, with inter-electrode impedance less than 3 kΩ (**42).**

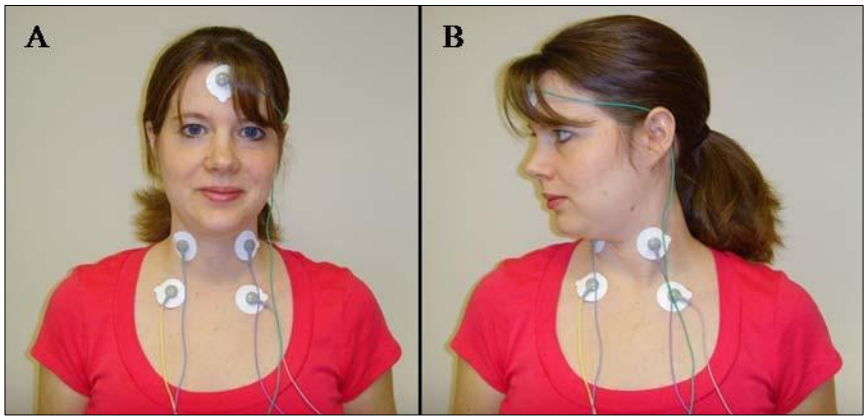

Figure (6): Electrode montage for cVEMP testing (**Hall et al., 2007).**

The best position to obtain continuous neck muscle contraction was chosen according to age. The youngest children were placed on a parent's lap, face-to-face, while the parent was instructed to support the lowest part of the child's back. The examiner slightly tilted the child backward, turning his/her head away from the stimulation side. This position led the child to straighten up and look at or reach for a toy presented on that side **(Wiener-Vacher et al., 2023).** With children over 6 years of age and Adults, the test is usually done either in the sitting position or in the lying down position. When done in sitting position, the patient is instructed to turn his head to contralateral side from the ear being tested. While conducting the test in the lying down position, the patient is made to lie down with head raised up of about 30 degrees without support and chin not touching the chest, and head turned contralaterally to the ear being tested to maximally activate the sternocleidomastoid muscle ipsilateral to the stimulation **(Rajguru., 2023**).

Stimulus parameters:

Air-conducted cVEMPs are more clinically used than bone conduction or galvanic stimulation due to their specificity of inducing a saccular response. Therefore, all further cVEMP information will be referenced to an air-conduction stimulus. The stimulus is presented at a loud intensity (e.g., 95 dBnHL) to determine the integrity of the saccule and its corresponding neurophysiologic mechanisms. Once function of the system is established, intensity is then decreased to search for a cVEMP threshold, which represents the softest intensity level a cVEMP tracing is existing and repeatable **(41).**

The air-conducted tone burst at 500 Hz, and clicks are the most extensively used stimuli. Acoustically responsive fibers in the vestibular nerve showed to be more responsive to frequencies between 500 and 1000 Hz, with little or no sensitivity to auditory stimuli above 3000 Hz With click stimulation, the intensity that was required to evoke VEMP was higher than tone burst about 95–100 dB above normal hearing level (140–145 dBSPL), which are comparatively uncomfortable for subjects **(41).**

Tone-burst evoked VEMP responses had lower stimulus thresholds, larger amplitude than click-evoked ones. Tone burst stimulation at 500 Hz tone was considered as an ideal stimulation, with the stimulus intensity that ranged between 95–105 dBnHL. Even though the tone burst stimulation at 95 dBnHL was the most frequently used, **(42)** found that 98 dBnHL stimulus improved rate of the responses and was comfortable to the subjects.

Recording parameters:

The main parameters that are usually recorded during a cVEMP testing are the presence or absence of a VEMP response, VEMP threshold (dBnHL), P1 and N1 latencies (ms) and P1–N1 amplitude (μV) **(43,44)**. Other parameters that can be derived from the main parameters are the interaural amplitude difference ratio which is calculated by dividing the interaural

difference of P13-N23 inter-amplitude by the sum of P13-N23 inter-amplitude of both ears **(43**).

Video Head Impulse Test

Video Head Impulse Test (VHIT) is a new objective quantitative test of vestibular function. It is a video-based clinical measure applied to detect the response of the vestibulo-ocular reflex (VOR) to angular head acceleration translations. It is used to measure the gain of the VOR and to distinguish refixation saccades (overt and covert saccades) which are detected by using sudden head impulses stimulations**.** VHIT is quickly applied, safe, repeatable, and provides objective quantitative data of each SCC separately and, therefore, of both vestibular nerve branches **(45).**

Eye movement recording:

Patients were tested in a well-lighted room with an eye-level target at a minimum distance of 1 meter in front of them. Subjects are placed in a height-adjustable chair, so that their head is at the ideal height for the clinician to deliver horizontal or vertical impulses. For results to be valid, VHIT goggles slippage must be minimized, and so the VHIT goggles were tightened on the head until movement of the goggles at the bridge of the nose was an absolute minimum, as tested by a gentle lateral pull on the goggles by the operator **(46).**

Measured parameters

Gain: A relative parameter was created and defined as gain symmetry (Gs) from the gain value obtained for rightward head-impulses (Gr) and leftward head-impulses (Gl) using the formula: Gs = [(Gr- Gl)/ (Gr+ Gl] ×100 **.** The normative values of VOR gain = Eye Move/Head Move ≈ 1.A normal result is defined by gain > 0.6 without saccades which represent a well-organized reflex, indicating that the response speed of the eye is nearly identical to the head movement. Abnormal results were of two types: normal gain with corrective saccades and low gain (<0.6) either with or without saccades **(45).**

Catch-Up (Refixation) Saccade: Catch-up saccades are very short-lived eye movements to re-center the patient's eye to the target of interest after they have lagged behind in response to the initial head impulse. Catch-up saccades that occur after head impulses are called overt saccades. Catch-up saccade that occurs during head impulses is called covert saccades **(47).** Catch-up saccades occur within a specific time window after the onset of head impulse. Covert saccades have extremely short latency within the range of so-called “express saccades” (<100 ms) and occur during the head movement phase. On the other hand, overt saccades have larger latencies and occur after the end of head motion (150-250 ms). Covert saccades are probably triggered by vestibular signals as vision is masked during a head impulse. Overt saccades are usually made after the head has come to rest, and consequently have a visual trigger, but might also be motivated by vestibular signals. Presence of

consistent catch-up saccades should be considered abnormal even when the VOR gain is within normal limits **(48).**

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