Vestibular Examination of Children With Alterations in Balance (I): Clinical and Instrumental Examination Methods

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Abstract
This is a review of the normal methods for vestibular examination, both clinical and instrumental, to evaluate the vestibular system. Emphasis is given to the examination sequence and objectives in each method.
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Keywords: Dizziness; Vestibulo-ocular reflex; Positional vertigo

PALABRAS CLAVE
Vértigo; Mareo; Inestabilidad; Reflejo vestibulo-oculomotor; Postura Vertigo

Exploración vestibular de niños con alteraciones del equilibrio (I): métodos de la exploración clínica e instrumental

Resumen
Se realiza una revisión de los métodos de la exploración vestibular oculomotora, postural y de las habilidades matricia necesarias para el equilibrio. Se hace hincapié en la secuencia de exploración y objetivos de cada método.
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Introduction
Balance alterations in children are not comparable to those of adults mainly because the aetiology is different, with a predominance of benign paroxysmal positional vertigo (BPPV) of childhood and instability associated with otitis media with effusion. Neither must we forget that the response to vestibular damage through habituation and compensation is more efficient in children. Despite this, the initial clinical approach (anamnesis and clinical examination) is just as relevant as in adults and must be carried out in a systematic and structured manner. This work was prepared for the Congress of the European Society of Pediatric Otolaryngology held in 2010 in Pamplona, Spain.

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combine the four fundamental phenomena in this problem, the perceptual (vertigo), oculomotor (nystagmus), postural (instability) and vegetative (nausea and vomiting) with which to build a pathophysiological approach.

During the clinical examination, it is necessary to bear in mind that the results should be considered normal according to: (1) the child's age, (2) the maturation of vestibulo-ocular reflexes (VOR) and vestibulo-spinal reflexes (VSR), and (3) postural control. In general, we can say that the vestibular system is fully active at birth, but the saccadic system matures gradually until the age of 2 years. Therefore, fixing upon an object that appears in the visual periphery requires 2–3 saccades. The following system is ineffective at the beginning due to immaturity of foveal vision and lack of myelination, which is not complete until 5 months of age. Optokinetic nystagmus (OKN) is thus present from 6 months of age and already contains a slow following phase in the direction of the stimulus and a rapid phase (nystagmus) in the opposite direction; before 6 months, there is a tonic eye deviation (slow phase, first phase) without nystagmus. The VOR follows the same maturation programme as OKN but is subject to the controlling action of the visual system (visual–vestibular interaction), which will not be accurate and precise until the age of 10 months.

Ocular Motility and Spontaneous Nystagmus

The first few questions we ask about children are about their ocular motility: Do they move their eyes correctly? Is there nystagmus in primary or extreme positions of the gaze? Does visual fixation modify the above findings? If there is nystagmus, is it present from birth?

However, before answering these questions, if the child is helpful, a simple assessment of visual acuity can be made using a classic or modified Snellen chart with objects of interest to the child. In addition to giving information, the chart will make it possible to introduce the child to the exploration process in an entertaining, non-aggressive manner. Next, the head will be moved left and right, while requesting the child to continue reading or describing the figures; in this way, it is possible to measure “dynamic” visual acuity. This will be normal if the child keeps the same acuity at rest or loses 1 or 2 lines, whereas it will be abnormal if, during mobilisation, the child needs large optotypes (more than 3 lines) to maintain visual acuity. When dynamic visual acuity is abnormal, a bilateral vestibulopathy should be suspected, requiring an ocularmotor study and a basic vestibular reflex study.

The next step will be a complete exploration of the extrinsic ocular motility. This is controlled by pairs of muscles (straight and oblique) that cause eye movements on a voluntary basis and whose aim is to place the image of the object of interest in the area of greatest visual acuity, that is, the fovea. Saccades, following and fixing, will be studied. Saccades are studied between 2 points separated by a distance that allows the child to sweep an angle of 15–20°, observing the movement of both eyes; this study should not be too long, otherwise hypometria from inattention will quickly appear. Following an object of interest is the normal continuation of the previous study and the child should be helped to complete it by avoiding staring at the examiner. With the exception of age, the OKN can be explored with a tape showing objects of interest or a manual rotating drum. Both in following and OKN, we should pay attention to the complete absence of ocular movement or to the more subtle and frequent asymmetric response. This part of the study ends by analysing whether nystagmus appears during ocular convergence.

When nystagmus is observed while maintaining correct visual fixation, we should analyse whether it is a congenital nystagmus. This is present from birth, is usually pendular or even rotatory but without a defined rapid phase, does not alter visual acuity, disappears with convergence or when the direction of the gaze is somewhat deviated from the primary (which makes the child adopt a characteristic head position when attempting to minimise it); when looking upwards, it changes and becomes purely vestibular (with rapid and slow phases). Acquired nystagmus is vestibular and has a plane (horizontal, vertical or horizontal-rotary) and a direction (right, left, up, down, clockwise, counter-clockwise), making it possible to establish or initiate a differential diagnosis (Table 1). The situation changes when the nystagmus appears only when visual fixation is annulled: not only is it vestibular but is also possibly due to an alteration in the peripheral vestibular system, which includes the inner ear and the vestibular nerve.

Vestibulo-Oculomotor Reflex 1

How to know if the peripheral vestibular receptor is functioning normally? Exploration of VOR by clinical means is especially easy using the cephalic impulse or shake test described by Halmagyi and Gresty. A high-acceleration movement is applied to the head (low amplitude, high velocity) in one direction, while asking the child to look forward, fixing the stare on a close point. Under normal conditions, this causes a vestibular stimulus (amplifying or excitatory inertia-induced flow of the endolymph in the horizontal semicircular canal of the ear towards which the head moves) and a compensatory VOR moving the eye in the opposite direction. The end result is that the eye remains immobile in space, regardless of the displacement of the orbit. In case of a unilateral peripheral vestibular lesion, the reflex is incomplete or not proportionate to the degree of head displacement, so it is necessary to generate one or more saccadic movements in the direction opposite to the head movement to keep the eyes fixed on the desired point. This test can be performed on children from the age of 12 months and its results are sufficiently reproducible to provide highly useful information. Unfortunately, it is not easy to know the degree of canalicular paresis that represents an abnormal result, although in comparison with adults it may indicate a paresis of at least 40%.

Next, while sitting on a parent’s lap, the child is moved from side to side in the consultation chair; during this examination, which is usually well tolerated, the child wears Frenzel goggles or a videonystagmography mask momentarily to observe per-rotatory nystagmus. It may be easier to observe when it stops in one cycle, before resuming the movement in the opposite direction, mimicking post-rotatory nystagmus. The result is abnormal when no
nystagmus is observed during any of the movements, but there is no locator value either in terms of side (right/left) or system (peripheral/central).

Visual–Vestibular Interaction

What is the effect of visual fixation on the vestibulo-oculomotor reflex?

This part of the visual–vestibular interaction allows modification of the importance of each stimulation mode (visual or vestibular) during perception of self-motion. It occurs not only at the cortical level but also at the subcortical level. The latter is easier to explore and should be performed following the examination described above. To do this, children are asked to stare at their own extended thumb while they are moved left and right or, if more comfortable, looking at the observer who moves simultaneously with them. Under normal conditions, there should not be any nystagmus; but if pre-rotatory nystagmus shakes are observed while moving (such as when the movement takes place in darkness, without visual fixation), an alteration in the central vestibular pathway should be suspected.

This study can be done while performing the caloric and/or rotatory test, although given how important its information is, it is worth separating from those tests. If caloric stimulus is used, it should be noted that the period of completion of the response occurs after about 70–90 s from the start of the cold or warm air test. Visual suppression of calorically nystagmus is normal if the reduction of nystagmus intensity (according to the speed value of the slow phase of nystagmus) exceeds 50% of the previous value without visual fixation. A similar, more reliable study can also be carried out during rotational stimulation; when the child is allowed to stare at a light stimulus that moves together with him or her in the rotary chair, no nystagmus should be observed. Conversely, when the opposite is true, a central vestibular disorder should be suspected. Another way to carry out this assessment is to analyse the reduction in the value of the time constant of post-rotatory nystagmus when, after the stimulus has ended, the child is asked to bend the head forward; under such conditions, the time constant is reduced by more than 50% of the value obtained when this test is done in a sitting position. Especially, in young children (<5 years), there is a greater reliance of the vestibular system of the following and optokinetic (immature for that age) on the saccadic (more developed). Maturation in the VOR (decreasing gain, increased time constant and appearance of the fast component of nystagmus) reflects a complex maturation that makes the child more dependent on the visual system and therefore makes the visual–vestibular interaction more relevant. However, given that saccades and the fast component of nystagmus are generated in similar structures of the brainstem, plasticity in the saccadic system is conceivable extended until adolescence, since the maturation process of the latter extends into adolescence.

Head Shaking and Mastoid Vibration Nystagmus

Is it possible to reveal a nystagmus not observed hitherto? Does cephalic agitation similar to that caused during walking cause nystagmus?

Cephalic agitation and the use of a vibratory stimulus on the mastoid occasionally generate a nystagmus that may be useful in the pathophysiological interpretation of vestibular alterations in children. Unfortunately, there is no clear consensus on the sensitivity and specificity data for either head shaking nystagmus (HSN) or for that caused by vibration of the mastoid (MVN). Both of these tests offer pathological results depending on the disease under study, stimulus characteristics and response analysis methodology.

Head shaking is easy to perform and children are usually collaborative; particularly if carried out actively (the patient moves his or her head from side to side without examiner assistance) it is very useful to obtain greater specificity. Frenzel glasses or a nystagmus recording system are placed at the end of the movement and the response is analysed in terms of nystagmus direction and duration.
If registered, the initial slow phase velocity should also be measured. Nystagmus occurring when applying a vibratory stimulus to the mastoid, vertex and dorsal neck region represents a way to reveal a residual spontaneous nystagmus or nystagmus characteristic of the vestibular compensation process (it is a habituation nystagmus). There is no experience in its prevalence in children or in the frequency in the various forms of vestibular disease.

Positional Nystagmus

Benign paroxysmal positional vertigo (BPPV) has a precise clinical expression but is relatively rare in children; nevertheless, it is common to find a postural trigger for vertigo crises in children with BPPV, so it is always necessary to perform a precise examination of positional nystagmus.15 Almost always of post-traumatic origin BPPV in children is very rarely idiopathic. This is due to the anatomy of the inner ear in children, in whom the otolithic membrane and otocoria are considered to have a higher level of anatomical fixation between them and with the bony labyrinth than in adults. A strong head stimulus (such as trauma) is therefore necessary to detach otocoria with subsequent lithiasis.16 The examination should be thorough and complete (spontaneous nystagmus, in supine position, with and without hyperextension of the head, right and left lateral position and Dix-Hallpike manoeuvre), with Frenzel glasses. The evaluation should have 2 levels: (1) clinical, attempting to demonstrate the characteristics of the nystagmus (with associated vertigo) characteristic of BPPV in all its forms, and (2) electronystagmography or videonystagmography, which makes a detailed recording of the nystagmus characteristics. The high incidence of spontaneous and positional nystagmus in children without personal history of dizziness or vertigo (close to 20% of studied cases) should be borne in mind.17,18

Vestibulo-Oculomotor Reflex 2

When should a caloric or rotational test be carried out? Which stimulation technique is the most appropriate?

Both tests are essential for the study of VOR through receptor stimulation in the horizontal semicircular canal (HSC). The response in children is clearly different from that of adults: as children grow older, the reflex gain decreases and the time constant increases, reflecting a central modulation capacity of the response, which becomes progressively more efficient. In contrast, the fast phase of nystagmus, which is not generated in the vestibular nucleus but by neurons in the reticular formation of the brain stem, follows a maturation process with age that is manifested by changes in the frequency of nystagmus. With advancing age, it is easier to find the fast component of nystagmus to stimuli near the threshold (0.23–1 s⁻¹).19

The caloric stimulus may be water or air. Due to the peculiarities of the study, we must ensure that the quantity and/or flow and the temperature used are always identical for both ears. In the case of water, the methodology followed in adults can be used, although unfortunately it cannot be completed in a high percentage of children. It is almost impossible in children younger than 4 years and, in general, it is not completed in 16% of children of older ages.20 Consequently, a screening test can be carried out with water at a single temperature (30 or 44 °C) and low flow, or with icy water (10°C). Air seems to be better tolerated, can be completed in all children and the vestibular reaction is significantly less intense.21 A consistent nystagmus is generated with air at extreme temperatures (29 and 49 °C) alternately stimulating each ear for 40 s with a flow of 0.5l/min. With a 24-s latency, its average duration is up to 145 s. The completion period occurs at 60–90 s depending on whether the stimulus is cold or hot; response becomes irregular and scarcely assessable when nearing 110 s for the cold stimulus and 130 s for the hot stimulus.22 In exceptional cases (absence of conventional caloric response in a child in whom the clinical VOR examination also registered a lack of response), testing with icy water is of interest. For this test, it is advisable to use 2ml of ice water (at approximately 4 °C) and record the response. This stimulus is sometimes considered painful and every possible precaution should be taken when performing it; the normal response is a burst of nystagmus beating in the opposite direction with an initial slow-phase velocity of up to 15 s⁻¹ maintained for 20–30 s.

The test of choice in the follow-up of children is probably the rotatory. In this test, small children can sit on the lap of an adult to undergo the stimulus or they can sit alone after a certain age. If sitting alone, it is necessary to use the alert phenomenon to show the children that they are not alone in the study (sing with them count numbers and skip some, ask for simple results to mental tests, etc.). The results of conventional tests (harmonic and impulsive sinusoidal acceleration) have been described and validated, but each laboratory needs to have its own normal values.23 Both tests can be assessed qualitatively by counting the number of shaking nystagmus during acceleration in each direction, which reports the intensity and symmetry of the response. A quantitative assessment can also be made (if it is possible to calibrate the biological signal) by analysing the VOR gain, phase advance and time constant. Under normal conditions, there is no asymmetry in the value of the time constant and its value is approximately 13–15 s.

The appearance of pre-rotatory or post-rotatory nystagmus response with no response during the caloric test represents a disparity of great interest that occurs only in certain morphological abnormalities of the bony labyrinth. It occurs in patients in whom the vestibule is reduced to a cystic structure in which a certain otolithic response probably occurs, sufficient to generate nystagmus during the rotatory test.13

The combination of calorics and rotational tests in a study battery including postural exploration makes it possible to recognise the compensatory mechanisms (visual and somatosensory) that appear in children with bilateral vestibular hypofunction at early ages, as well as the difficulty of obtaining such compensation when the damage occurs in older age groups.

Otolithic Function

Vestibulosympathetic reflexes help to modulate and maintain posture with myotatic reflexes, through which
information or vestibular impulses are transmitted to motor neurons in the anterior horn of the spinal cord. The myotatic reflex is primarily responsible for controlling skeletal muscular tone in the trunk and limbs. It receives influences from (in addition to the vestibular system) other supraspinal centres, such as the basal ganglia, the cerebellum and the reticular formation. Although it cannot be specified that vestibulospinal function is caused by the action of the otoletic maculae in the utricle and saccule, it is clear that their role is paramount. Consequently, otoletic function and postural control tests should be carried out systematically in the context of motor development in children.

There are currently two ways of stimulating vestibular evoke myogenic potential (sound and vibration) and two ways of recording it (ocular and cervical). The stimulus may be vibratory, unique in the forehead, and the unilateral registration always infraorbital or in the sternocleidomastoid muscle. The ocular potential reflects stimulation of the macula of utricle and is always contralateral, while the cervical reflects that of the saccule and is ipsilateral.24 The test is easy and fast but the results in children are distinctly different from those in adults, particularly for children under 10 years of age. This requires a different evaluation for that age group.25 The differences between children and adults relate to p13 and n23 latencies, as well as the p13-n23 amplitude. The cut-off points for the latencies are consequently 12.6 and 19.8 ms, respectively.26

Motor Skills

Basic motor skills are those underlying more advanced and specific motor skills. The mature motor pattern of a basic skill is not related to age; the rate of progress in motor development is given by the joint influence of maturation, learning and external influences. Motor development is composed of the changes in motor behaviour that take place over time, reflecting interaction with the environment. Children experiment and gradually discover simple and individual skills, which gradually become mechanical and are combined and modified until they become true sporting abilities.27

Motor skills can be classified into: non-locomotor, locomotor and projection/reception:

- Non-locomotor: their main characteristics are managing and controlling the body in space: swaying, bending, stretching, bowing, turning, twisting, pushing, balancing, etc.
- Locomotor: walking, running, jumping, variations of jumping, climbing, ascending, descending, etc.
- Projection/reception: receiving, throwing, hitting, batting, catching, rolling, etc.

Balance is a factor in child motor skills that develops progressively so that, at 2 years of age, the child is already able to stand on a support for a short period of time. At 3 years, there is static balance (on one foot), which can be maintained for a few seconds, and dynamic balance (stability during walking on lines drawn on the floor), which becomes more complete at 4 years of age. Only after 7 years of age does balance no longer depend on visual information and is correct with closed eyes. From this point onwards, difficulty varies with the complexity imposed on the support base (characteristics, stability and amplitude or limits of stability), height of centre of gravity, number of supports, elevation above ground level and dynamism of exercise. Listing all the factors one by one is impossible, but they must be taken into account when examining children.

Walking is a natural form of vertical locomotion. Gait, as executed by bipedal humans, requires both anatomical integrity and functional integrity of the frontal cortex, pyramidal tract, extrapyramidal system, balance organs and pathways, muscle coordination, posterior cords, peripheral nerves and muscles. The motor pattern is characterised by an alternating, progressive action of the legs and continuous contact with the supporting surface. The complete cycle of the motor pattern, one step, consists of a suspension phase and a support or contact phase with each leg. Children cannot move in a vertical position without assistance until they have developed sufficient muscular strength, appropriate antigravity reflexes and effective balance.

Gross motor skills designate the movement of the head, body, legs, arms and large muscles mentioned above. The emergence of gait in the second year frees the hands to acquire fine motor skills, that is, those including small body movements that also require excellent coordination and control: as in the case of gross motor skills, their acquisition is a continuous, gradual process. Some examples are: reaching for and grasping objects, taking them to the mouth (which requires coordination), the pincer movement that starts at the end of the first year of life (the ability to manipulate objects is greatly expanded once this movement has been mastered), completing simple puzzles or copying simple geometrical figures. Between the ages of 10 and 12, children start to use manipulative skills similar to those of adults.

The exploration of posture and gait must follow these elements in order:

- Posture. (1) Trunk: Under normal conditions, gait is carried out with a straight trunk. (2) Standing: When children stand still in the Romberg position, we observe the amplitude of their base, oscillating movements and the ability to balance on both legs. Vision is extremely helpful in maintaining a correct standing position, so that after a certain age closing the eyes causes a slight but significant increase in body swing movements. (3) Postural reflexes: Those which enable and facilitate balance in an upright posture. These are explored in a simple manner when children, standing upright, are nudged in any direction. In some cases, immaturity or loss of these reflexes causes the child to lose balance with a minimal push.

The clinical test of sensory interaction and balance imitates the conditions of the dynamic posturography presented below. Children must perform 6 tests or conditions: the first 3 on a firm surface and the last 3 on foam, which makes proprioceptive information inaccurate. Conditions 1 and 4 are carried out with open eyes, 2 and 5 with closed eyes (eliminating visual information), and 3 and 6 with the child facing a flat surface attached to her or his head, which makes peripheral visual function inaccurate for balance; the aim in all conditions is to maintain stability for at least 30 s.28
Each condition should be repeated 2 or 3 times at random, so as to prevent the phenomenon of adaptation, which could falsely improve the results. The condition of tandem foot position can also be used to add sensitivity to this test.

- **Gait.** (1) Start: Under normal conditions, there is a body rotation towards the side which stays behind, to relieve weight on the limb that will be lifted and move the foot while maintaining the pelvis at a right angle to the first limb. (2) Development: While gait is being conducted, we can assess the step length, frequency and speed. (3) Associated movements: When the child is walking, we can note a synergistic set of movements of the head, trunk and upper extremities.

Motor skills can be examined in two adequately validated tests such as the peabody developmental motor scale (PDMS), which analyses various categories of skills and is a reliable test of the motor function of the child, and the Bruininks–Oseretsky test of motor proficiency (BOTMP).

The PDMS enables assessment of the motor development of children up to 5–6 years in various subtests: reflexes, static balance, locomotion, object manipulation, grip and visuo-motor integration. The first 4 comprise the Gross Motor Index and the last 2, the Fine Motor Index. How socialisation, age, parental schooling level and economic level affect results is controversial; in general, it seems that girls show greater ease in performing fine motor tasks and boys in gross motor skills. There is an improved version which analyses fine motor skills (PDMS-2-FM) for children up to age 6 in 98 items grouped into 2 subtests: visuo-motor integration and gripping. Its management improves if the response to the performance of a skill is dichotomous and there are items which deviate the objective or the characteristics of the subgroups and which could be ignored (e.g. item 16 “handling paper” in the gripping section, item 55 “turning a page” in the visuo-motor integration section); but it is generally a good tool to measure these motor skills.

The BOTMP makes it possible to measure gross and fine motor skills. It has 46 items divided into 8 study categories: agility, balance, bilateral coordination, strength, coordination between the upper limbs, response speed, visuo-motor control and upper limb speed and laterality. Bilateral coordination is an interesting category in cases of children who show poor coordination between the two sides of the body, problems in crossing the midline, problems developing a specific right-left preference, etc. The balance section is a specific portion of the test (BOT2) which can be implemented in consultations on children with vertigo and other ear alterations that may affect the vestibular system. It is a screening test for static balance (3 items; on one leg) and dynamic balance (5 items; execution of gait movements without external influences) although some more can also be added. Table 2 shows the study conditions or 9 items which constitute it, the implementation times and their conversion into a numeric value. The BOTMP has good reliability (test–retest; r=0.56) and moderate internal consistency (r=0.67). Data are given as overall (out of 37) and as age, as months in advance or delay with respect to chronological age.

### Table 2 Balance Subtest in the Bruininks–Oseretsky Test of Motor Proficiency.

<table>
<thead>
<tr>
<th>Visual Condition</th>
<th>Completed (max)</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stability on two separated feet</td>
<td>EO 10 s</td>
<td>0–4</td>
</tr>
<tr>
<td>Walking forwards</td>
<td>EC 10 s</td>
<td>0–4</td>
</tr>
<tr>
<td>Stability standing on one foot</td>
<td>EO 10 s</td>
<td>0–4</td>
</tr>
<tr>
<td>EC 10 s</td>
<td>0–4</td>
<td></td>
</tr>
<tr>
<td>Tandem walk</td>
<td>EO 6 steps</td>
<td>0–4</td>
</tr>
<tr>
<td>Stability standing on one foot</td>
<td>EO 10 s</td>
<td>0–4</td>
</tr>
<tr>
<td>on a rail or balance beam</td>
<td>EC 10 s</td>
<td>0–4</td>
</tr>
<tr>
<td>Tandem position on a rail or balance beam</td>
<td>EO 10 s</td>
<td>0–5</td>
</tr>
<tr>
<td>Total score</td>
<td></td>
<td>0–37</td>
</tr>
</tbody>
</table>

EC: eyes closed; EO: eyes open.

### References

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