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Review article

Assessment of functional development of the otolithic system in growing children: A review

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ABSTRACT

Objectives: Although the caloric test, rotational test, and posturography have been used to investigate balance function conventionally, and they are older than tests of otolithic organs, yet it seems that most clinicians are less familiar with the development of otolithic (saccular and utricular) function in children. This study reviewed the electrophysiological testing used to assess the functional development of the otolithic system in growing children.

Methods: Based on the literature, studies of cervical vestibular-evoked myogenic potential (cVEMP) and ocular VEMP (oVEMP) tests in children ranging from newborns, small children to adolescents were reviewed. Papers concerning foam posturography in children were also included.

Results: The cVEMPs can be elicited in newborns at day 5, whereas the oVEMPs are absent in neonatal period. When children grow to 2 years old, the oVEMPs can be induced with eyes closed condition, while the oVEMPs with eyes up condition can be elicited in children aged >3 years old, with the characteristic parameters similar to adult levels. In contrast with cVEMPs, it is until the neck length >15.3 cm (aldolesence), one need not account for neck length in evaluating cVEMP latency. Additionally, foam posturography indicated by the Romberg quotient of the sway velocity/area on foam pad is considered to reflect the otolithic function, which reached adult levels when the children at 12 years old.

Conclusions: For the functional development of the otolithic system in growing children to approach adult levels, the earliest occurrence is the oVEMP test, followed by the foam posturography, and cVEMP test.

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Abbreviations: ABR, auditory brainstem response; ACS, air-conducted sound; BCV, bone-conducted vibration; COP, center of pressure; cVEMP, cervical VEMP; DTI, diffusion tensor imaging; EMG, electromyography; FL, force level; oVEMP, ocular VEMP; RQ, Romberg quotient; SCM, sternocleidomastoid; SVH, subjective visual horizontal; SVV, subjective visual vertical; VEMP, vestibular-evoked myogenic potential; VOR, vestibulo-ocular reflex.

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1. Introduction

The human balance system consists of multisensory and sensorimotor networks, such as visual, vestibular, somatosensory and cerebellum systems [1]. These systems are anatomically developed in a growing child and responsive after birth. For instance, the human labyrinth reaches its adult size at 17–19 weeks of gestation, and the vestibular end organs such as semicircular canals and otolithic organs (utricle and saccule) are structurally well differentiated at birth [2,3].

Conventionally, investigation of the balance function in children includes caloric test, rotational test, and tests for postural control [4,5]. Lack of vestibular input has been shown to delay the acquisition of motor skills. Infants with vestibular dysfunction eventually achieve motor milestones, i.e. delay in the head control and independent walking [6,7]. Children with vestibular hypofunction eventually learn to use their weak vestibular signals to generate appropriate motor responses [8]. However, poor postural control is not specific for vestibular dysfunction.

The vestibular system is anatomically developed and functionally responsive by birth [9]. For investigating the vestibulo-ocular reflex (VOR) system, both caloric and rotational tests are conducted. The caloric test is poor in neonates 24–120 h old, but normalizes by 2 months of age and matures further during the first 2 years of life [4]. Notably, small children have poor tolerance of the caloric test which can evoke nausea/vomiting with the risk of aspiration. Thus, the caloric test is usually performed in children aged >5 years old.

In contrast, the rotational test is most useful in determining the presence of bilateral peripheral vestibular loss [5,10]. The majority of normal children demonstrate vestibular responses to the rotational test by age 2 months. By age 10 months, the absence of VOR responses can be considered abnormal [4], and the rotational test is relatively more suited to children aged <3 years old. Nevertheless, limitation of the rotational test is that a rotary chair is not always available in each laboratory [11–13].

Like the caloric and rotational tests evaluate the rotational VOR system, the otolithic test assesses the translational VOR system. In the last century, several behavior tests for otolithic function have been proposed, namely ocular counter rolling test, off-vertical axis rotation test, subjective visual horizontal/vertical (SVH/SVV) test, parallel swing test, etc. [14–18]. With sustained lateral head tilt the eyes counter-roll, presumably as part of an attempt to align the horizontal meridian of the retina with the horizon. This is called counter-rolling of the eyes [14]. In contrast, otolith-ocular reflexes can also contribute to the VOR during head rotations, if the axis of rotation is titled away from the earth-vertical axis, so-called off-vertical axis rotation [15]. In such circumstance, the otoliths are continuously stimulated by the changing gravity vector associated with rotation of the head [16]. However, these behavior tests failed to gain the popularity probably because instrumentation is not available in each laboratory, or test results contaminated with multiple confounding factors. For example, subjects may find visual cues to adjust their estimation of SVH/SVV during the test [19]. Most of all, some behavior tests cannot be performed in small children. Thus, despite the caloric and rotational tests have been used to investigate balance function conventionally, and they are older than tests of otolithic organs, it seems that most clinicians are less familiar with the development of otolithic function in children.

By stimulating the ear with air-conducted sound (ACS) or bone-conducted vibration (BCV), vestibular-evoked myogenic potential (VEMP) can be recorded on the contracted neck muscles, termed cervical VEMP (cVEMP), and on the extraocular muscles, termed ocular VEMP (oVEMP) [20,21]. These two emerging tests are recently adopted to explore the dynamic otolithic function, adding a potential usefulness to study the sacculo-collic and utriculo-ocular reflexes in children [22–25].

Additionally, posturography is used for global testing of human balance function with the subject standing on a foam pad (foam posturography) or a moving platform (dynamic posturography). To exclude both visual and somatosensory inputs, the foam posturography with eyes closed condition is utilized for evaluating the vestibular function [26–29], and the Romberg quotient (RQ) of the sway area on foam pad is considered to reflect the otolithic function [30,31]. Restated, the posturography is designed to evaluate and record postural balance status, and is often coupled with vestibular test battery to identify sensory input deficits and assess functional development of the vestibular system in children [27,31].

Clinically, assessing cVEMPs in small children may help evaluate the development of the sacculo-collic reflex system, which detects changes in head position relative to gravity during early life. In contrast, maturation of the otolithic-ocular reflex evaluated by oVEMP test is mandatory for assessing the development of independent gait in small children. This study thus reviewed the electrophysiological testing used to assess the functional development of the otolithic system in growing children. This evidence-based assessment was developed from peer-reviewed articles obtained through the MEDLINE database of the US National Library of Medicine.

2. Assessment of otolithic function

2.1. Cervical VEMP test

The cVEMP test has been validated for assessing the saccular function in recent years [20]. It is generated via a disynaptic pathway, originating in the saccule and proceeding along vestibular afferent fibers to the vestibular nuclei, then via rapidly conducting projections that synapse with sternomastoid nuclei [32].

2.1.1. Procedure

The subject was in a supine position. Two active electrodes were placed on the upper half of the sternocleidomastoid (SCM) muscles, one reference electrode was positioned on the suprasternal notch, and one ground electrode was situated on the forehead (Fig. 1). Surface potentials, predominantly electromyographic (EMG)