

1 Vestibular Assessment in the Pediatric Population

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3 **Running title**

4 Pediatric vestibular examination

5 **Authors**

6 Cleo Dhondt (MSc),¹ Ingeborg Dhooge (PhD, MD)^{1,3} and Leen Maes (PhD)^{2,3}

7 ¹ Faculty of Medicine and Health Sciences, Department of Otorhinolaryngology, Ghent

8 University, Ghent, Belgium

9 ² Faculty of Medicine and Health Sciences, Department of Speech, Language and Hearing

10 Sciences, Ghent University, Ghent, Belgium

11 ³ Department of Oto-rhino-laryngology, Ghent University Hospital, Ghent, Belgium

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15 **Corresponding Author**

16 Cleo Dhondt, Ghent University, Department of Otorhinolaryngology, Ghent, Belgium

17 E-mail: Cleo.Dhondt@UGent.be; Phone: 0032 9 332 28 89

18 Postal address: Ghent University Hospital, Department Otorhinolaryngology, Corneel

19 Heymanslaan 10 (1P1), B – 9000 Ghent, Belgium

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24 assistance in collecting the data.

25

26 **INTRODUCTION**

27 Vestibular disorders in children are not as uncommon as generally assumed. Prevalence rates
28 vary from 0.7 to 15%¹, although certain groups (e.g. with congenital TORCH-infections,
29 prematurity and/or hearing loss) are known to be at higher risk for vestibular dysfunctions²⁻⁶.
30 Moreover, recent studies suggest that the impact of vestibular dysfunctions may be greater than
31 previously thought and may not be limited to delayed (gross) motor development⁷, but also be
32 accompanied with learning difficulties⁸ (e.g. reading, writing) or cognitive deficits⁹ (e.g.
33 visuospatial orientation, attention). In young children (<6yr), both history taking and vestibular
34 assessment are challenging: children report vague symptoms lacking the appropriate
35 vocabulary to describe their complaints¹⁰, vestibular tests are not very child-friendly and the
36 available equipment is not adapted to the pediatric population¹¹. The aim of this paper is to
37 propose simple adjustments to create a child-friendly version of the standard vestibular
38 assessment which provides objective information on the function of the different parts of the
39 vestibular system.

40

41 **METHODS**

42 **Subjects**

43 Fifty-eight healthy subjects (35 girls, 23 boys) between 5 months and 6 years of age were
44 divided into six age categories, each containing eight children. As greater variation was
45 expected amongst the youngest subjects (5mo-1yr), 18 subjects were recruited for this group.

46 The study was approved by the Ghent University Hospital's Ethics Committee. Informed
47 consents were obtained from the children's parents.

48 **Test protocol**

49 In our hospital, patients at risk for vestibular dysfunctions (with hearing loss, congenital
50 cytomegalovirus infection, cochlear implant and/or vestibular symptoms) are subjected to an
51 extensive vestibular test protocol as summarized in Table 1. This examination is preceded by
52 thorough history taking guided by questionnaires and accompanied with ocular motor testing
53 to identify central vestibular disorders, and motor assessment to determine the impact on the
54 motor development⁷. This extensive assessment should provide good insight in the vestibular
55 function and allow appropriate referral to other specialists (e.g. neurologist, physiotherapist), if
56 needed.

57 Children between 5 months and 3 years of age are examined with the video Head Impulse Test
58 (vHIT), rotatory test and cervical Vestibular Evoked Myogenic Potential (cVEMP) test. These
59 three tests allow a quick and child-friendly evaluation of both the canal and otolith system.
60 Moreover, the results are not affected by possible middle ear pathologies, which are frequently
61 present in young children. From the age of three, the test battery is extended with four caloric
62 irrigations and the ocular Vestibular Evoked Myogenic Potential (oVEMP) test, since
63 prolonged alertness and cooperation are more feasible in this older age category.

64 The sequence of examinations (Table 1) in younger children (<3yr) is mainly tied to the
65 required level of alertness and cooperation, as these are particularly limited in this group and
66 have a substantial effect on test-reliability. In older children (>3yr), tests are ranked by
67 increasing invasiveness.

68 **Adjustments for children**

69 *vHIT (semicircular canal)*

70 The Synapsys (Marseilles, France) vHIT Ulmer device is ideal for application in children as no
71 calibration is needed prior to registration and it does not require wearing goggles. One
72 examiner, placed behind the registering stand-alone camera, attracts the child's attention to an
73 appealing visual stimulus (toy). The other examiner, placed behind the child, performs the head
74 maneuvers (Fig. 1a). Consequently, one can always rely on the subjective evaluation by the
75 examiner behind the camera in case objective measurement fails. In our clinic, vHIT standardly
76 entails lateral canal testing. Adding vertical canal testing is dependent on clinical indications
77 (e.g. history taking, imaging results) and the child's cooperation as it is more challenging and
78 time-consuming than lateral canal testing. Normative data for children have recently been
79 published by Wiener-Vacher and Wiener¹².

80 *Rotatory test (lateral semicircular canal)*

81 The child is seated in a car seat on the rotatory chair, the head fixed by a neck pillow and
82 headband (Fig. 1b). An examiner walks along with the chair, keeping the child comforted but
83 aroused and aware of the presence of an adult (especially important with hearing-impaired
84 children). Alertness is stimulated by music playing through a speaker attached to the rotatory
85 chair. Electronystagmography (ENG) is preferred over videonystagmography to register eye
86 movements, since ENG-measurements are not interrupted by closing the eyes and it does not
87 require wearing goggles, which are generally not well-tolerated and not well-fitted for children.
88 The latter would result in incomplete darkening and the possibility of fixation during testing.

89 *cVEMP (sacculle)*

90 To bypass possible middle ear disorders, the cVEMP-test is performed with bone conduction
91 (59 dB nHL/129 dB SPL). Subjects are tested in supine position, the upper body placed upon a

92 sloping pillow and the head turned and supported by only the examiner's hand (Fig. 1c). The
93 child is stimulated to turn the head by placing the parent at the side of the non-test ear, provided
94 with toys.

95 *Caloric test (lateral semicircular canal)*

96 In order to increase the feasibility of the caloric test, we reduced the deviation from body
97 temperature from 7°C to 5°C. In our experience, these temperatures (32°C and 42°C) are better
98 tolerated than the standard temperatures (30°C and 44°C), increasing the chances of tolerating
99 four irrigations and obtaining the complete caloric response diagram. Cold irrigations are
100 performed first, so that at least one irrigation in each ear can be completed in case the child
101 shows increasing resistance during warm irrigations. Water is preferred as stimulus because it
102 induces better responses, although air insufflation can be a valuable alternative in very young
103 children (<3yr) as tympanostomy tubes are common in this group and air insufflation may be
104 perceived as less invasive than water.

105 *oVEMP (utricle)*

106 An air conduction stimulus (95 dB nHL/119 dB SPL) is used since the maximal intensity of a
107 standard bone conductor is insufficient and a mini-shaker is not well-tolerated by young
108 children. A bone conductor combined with a special amplifier reaching higher intensity levels
109 could be a valuable alternative. An upward gaze of 30° is elicited using a smartphone attached
110 to the wall, playing a video clip.

111

112 **RESULTS**

113 Table 2 gives an overview of the success rates of the vestibular tests across the different age
114 categories. Causes of failure or unreliability of the test results are summarized in Table 3. The
115 duration of the vestibular test protocol was approximately 1 hour for the abridged protocol in
116 younger (<3yr) children and 2 hours for the extensive protocol (>3yr).

117

118 **DISCUSSION**

119 In literature, as well as in clinical practice, insufficient attention has been given to vestibular
120 assessment in the pediatric population. Centers that do perform vestibular examinations in
121 young children often confine themselves to a limited test protocol (e.g. only cVEMP) or less
122 accurate evaluation techniques (e.g. subjective measurements instead of quantitative
123 interpretation of the response parameters).

124 The results of this paper show that vestibular assessment with an extensive test protocol using
125 objective measures is feasible in young children when some adjustments are made. As
126 summarized in Table 2, the assessment of children between the ages of 2 and 3 years seems to
127 be the most challenging, as their cooperation can be limited and they may be alarmed by the
128 unfamiliarity of the test situation. It should be noted that the subjects in this study were healthy
129 voluntarily-participating children. In patients with vestibular complaints, parents could show
130 more dedication to persevere with the examinations, as they hope to find some answers in the
131 test results. Concerning the test protocol in children younger than three, the rotatory test appears
132 to be the most difficult to conduct reliably. When the extensive protocol for older children is
133 considered, the caloric test remains the most challenging, reaching higher success rates as the
134 child grows older. Consistent with the consensus in literature, the highest success rates for the
135 VEMPs demonstrate that these are the most feasible vestibular tests in the pediatric
136 population¹³. The relatively new vHIT is also promising as it is fast, child-friendly, easy to

137 conduct, and it provides ear-specific information about the semicircular canal system. Despite
138 its non-invasive character, success rates of vHIT are still lower compared to VEMPs. This is
139 because the vHIT requires more cooperation (fixating the target, enduring holding the head)
140 and registration is impossible in case of crying or persistent eye blinking. The latter is the main
141 cause of failure in older subjects (>3yr) as was the case in our study in one 4-year-old child.
142 Note that vHIT-testing is applicable for typically developing infants from the age of 5 to 6
143 months, as active head control is required to obtain a safe and reliable measurement.

144 Objective and extensive vestibular examination is indispensable to enable detailed and accurate
145 evaluation of vestibular function. Comparison of the patient's results with normative data of a
146 healthy control group makes more clear-cut conclusions and early identification of (even
147 partial) vestibular dysfunctions possible. Apart from these inter-subject comparisons, objective
148 measurements also allow more meaningful interpretations of intra-subject comparisons (i.e.
149 follow-up assessments). Therefore, vestibular examination should be more established in the
150 pediatric population for patients with an increased risk for vestibular deficits²⁻⁶ (e.g. with
151 congenital TORCH-infections, prematurity and/or hearing loss) and/or vestibular complaints¹⁴.
152 This should ensure early identification and referral for vestibular rehabilitation in order to
153 facilitate the child's early development^{15,16}.

154

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157 Rombaut for the practical insights during the development of the pediatric test protocol and
158 Heleen Goeminne, Amber Vanhoutte, Heleen Van Der Biest and Laura Leysens for their
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202 exercise in two children with vestibular hypofunction. Int J Pediatr Otorhinolaryngol.
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204

205 **FIGURES**

206 **Fig. 1.** Test setup of the minimal pediatric test protocol for children younger than three. a)
207 Video Head Impulse Test in a seven-month-old child. The examiner behind the registering
208 stand-alone camera is attracting the child's attention to an appealing visual stimulus. The
209 examiner placed behind the child is performing the head maneuvers. b) Rotatory test in a five-
210 month-old child. The child is seated in a car seat, with the head fixated by a neck pillow, a
211 headband and additional manual fixation by the examiner walking along, if necessary. c)
212 Cervical Vestibular Evoked Myogenic Potential test in a one-year-old child, placed upon a
213 sloping pillow and the head turned and supported by only the examiner's hand.



214

215

216 **TABLES**

217 **Table 1.** Pediatric vestibular test protocol

5 months – 3 year	3 year – 6 year
1. vHIT	1. vHIT
2. Rotatory Test	2. cVEMP
3. cVEMP	3. oVEMP
	4. Rotatory Test
	5. Caloric Test

vHIT = video Head Impulse Test; cVEMP = cervical Vestibular Evoked Myogenic Potentials; oVEMP = ocular Vestibular Evoked Myogenic Potentials

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219

220 **Table 2.** Representation of the proportion of children across the different age categories in
 221 which each test could be successfully and reliably conducted

Age category	Subjects	Median	Success rate (%)				
		age (mo)	vHIT†	cVEMP	oVEMP	Rotatory test	Caloric test
5mo-1yr	n=18	7,0	72,2	100,0		88,9	
1yr-2yr	n=8	17,0	100,0‡	100,0		62,5	
2yr-3yr	n=8	29,0	85,7‡	75,0		50,0	
Total group <3yr	n=34	10,5	81,3	94,1		73,5	
3yr-4yr	n=8	44,0	100,0	100,0	100,0	100,0	62,5
4yr-5yr	n=8	54,5	87,5	100,0	100,0	100,0	85,7§
5yr-6yr	n=8	67,5	100,0	100,0	100,0	100,0	100,0
Total group >3yr	n=24	54,5	95,8	100,0	100,0	100,0	82,6

†In this table, only success rates of the lateral vHIT are shown. ‡ Data of 1 vHIT registration in 2 age

categories are missing due to a technical issue. § In 1 patient, the data of the caloric test is missing as the test was not performed due to the presence of tympanostomy tubes.

vHIT = video Head Impulse Test; cVEMP = cervical Vestibular Evoked Myogenic Potentials; oVEMP = ocular Vestibular Evoked Myogenic Potentials

222

223 **Table 3.** Causes of unreliability of the obtained test results or failure of conducting the
 224 vestibular tests

	vHIT	cVEMP	oVEMP	Rotatory test	Caloric test
Impossible	- Crying - Constant blinking - Not tolerating holding the head	- Severe protest (pulling of electrodes, not staying in position)	Not applicable	- Severe protest (pulling of electrodes, excessive head movement, failure of calibration)	- Fear
Unreliable	- Insufficient number of accepted vHIT-sequences - Large variation in gain-values - Unacceptable vHIT-traces	- Impossibility of re-duction of the cVEMP-response (severe protest)	Not applicable	- Head movement - Falling asleep - Insufficient reaction due to severe protest (squeezing the eyes)	- Tolerating only 2 (cold) irrigations

vHIT = video Head Impulse Test; cVEMP = cervical Vestibular Evoked Myogenic Potentials; oVEMP = ocular Vestibular Evoked Myogenic Potentials

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229 **SUPPORTING INFORMATION LEGEND**

230 **Video 1.** Video Head Impulse test in a subject younger than three

231 Filename: Video_1_SuppInfo.mp4

232 **Video 2.** Video Head Impulse test in a subject older than three

233 Filename: Video_2_SuppInfo.mp4

234 **Video 3.** Rotatory test in a subject younger than three. Note that this video was recorded in an
235 illuminated room for demonstration purposes. Evidently, the actual examination is performed
236 in complete darkness.

237 Filename: Video_3_SuppInfo.mp4

238 **Video 4.** Rotatory test in a subject older than three. Note that this video was recorded in an
239 illuminated room for demonstration purposes. Evidently, the actual examination is performed
240 in complete darkness.

241 Filename: Video_4_SuppInfo.mp4

242 **Video 5.** Cervical Vestibular Evoked Myogenic Potential test in a subject younger than three

243 Filename: Video_5_SuppInfo.mp4

244 **Video 6.** Cervical Vestibular Evoked Myogenic Potential test in a subject older than three

245 Filename: Video_6_SuppInfo.mp4

246 **Video 7.** Ocular Vestibular Evoked Myogenic Potential test in a subject older than three

247 Filename: Video_7_SuppInfo.mp4

248 **Video 8.** Caloric test in a subject younger than three. Note that this video was recorded in an
249 illuminated room for demonstration purposes. Evidently, the actual examination is performed
250 in the dark.

251 Filename: Video_8_SuppInfo.mp4

252 **Video 9.** Caloric test in a subject older than three. Note that this video was recorded in an
253 illuminated room for demonstration purposes. Evidently, the actual examination is performed
254 in the dark.

255 Filename: Video_9_SuppInfo.mp4