Chap 4 Laboratory examinations and imaging

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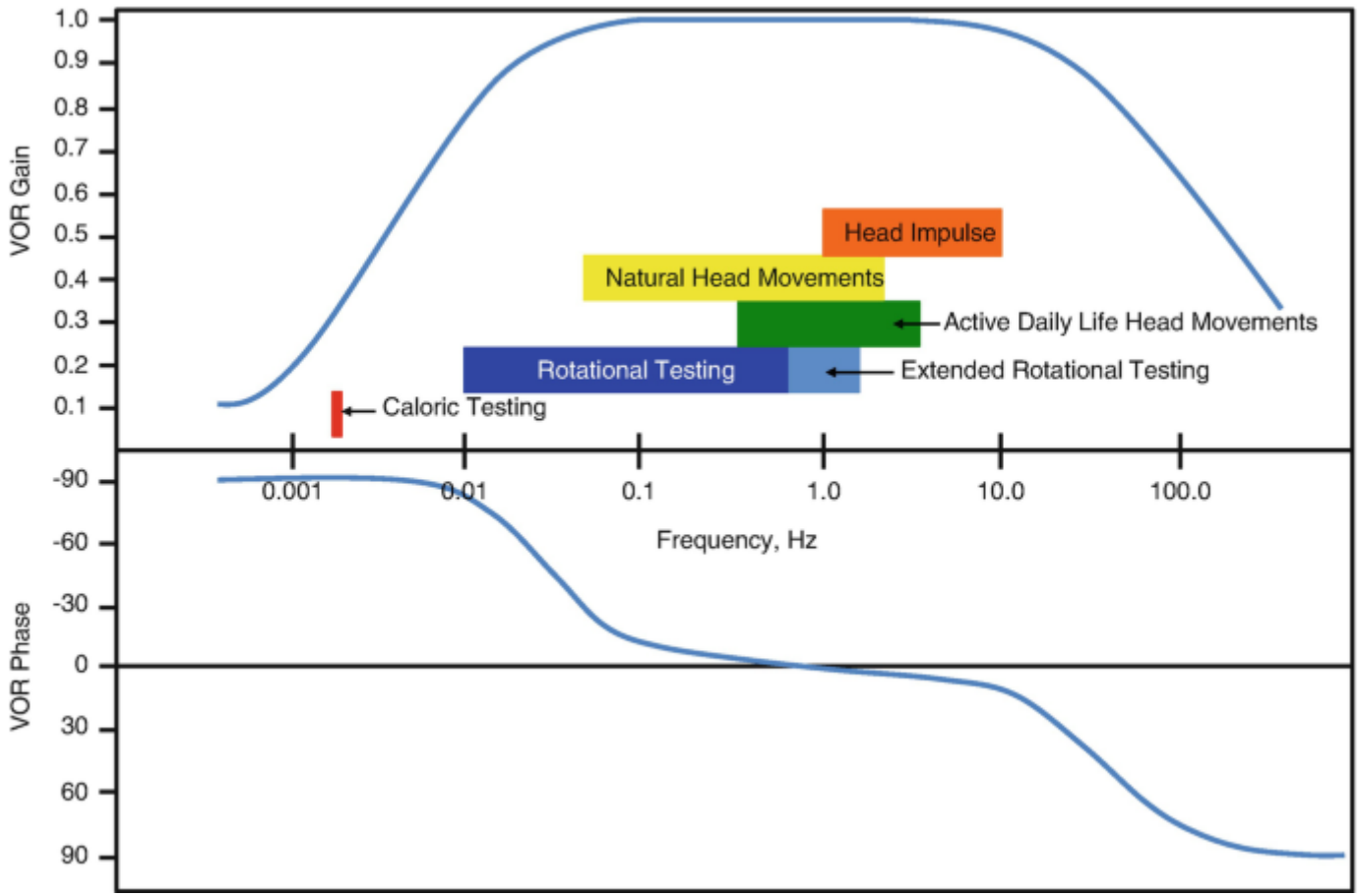
Table 4.1 Laboratory examinations of the vestibular and ocular motor systems

Technique	Features	Advantages	Disadvantages
Vestibular system			
Video-HIT	Quantification of the function of the angular VOR in the high-frequency range	Non-invasive, can be performed quickly and easily, examination of the VOR function close to the optimal range of stimulation of the semicircular canals between 0.1 and 10 Hz	This test does not allow examination of a single semicircular canal, but only a pair of semicircular canals
Caloric testing	Quantification of the function of the horizontal semicircular canals in the low-frequency range	Non-invasive, simple to perform, allows the examination of single horizontal canals	Only the function of the horizontal canals can be quantified, time-consuming, there can be several artifacts; it may cause nausea or vomiting in patients
Rotatory chair examination	Quantification of the function of the horizontal semicircular canals in the lower- and middle-frequency range	Non-invasive	Expensive equipment, only possible to examine pairs of semicircular canals, not single canals (similar to video-HIT); indicated in selected cases when video-HIT and caloric testing are normal, although the patient history indicates a peripheral vestibular deficit. Nowadays, only rarely applied.

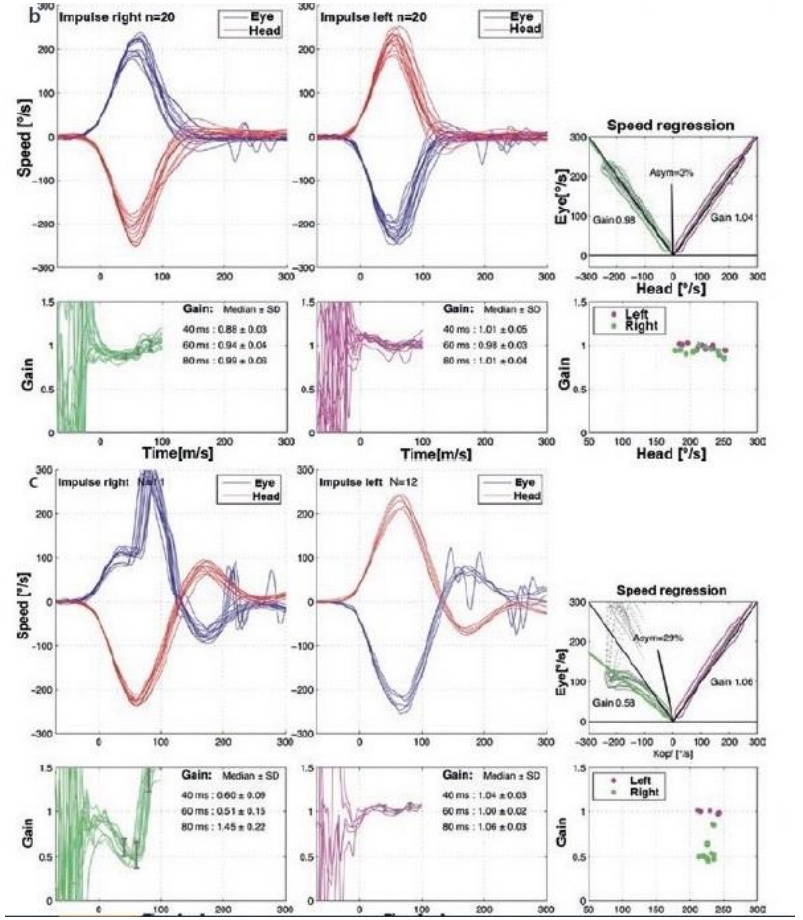
(continued

Technique	Features	Advantages	Disadvantages
Cervical vestibular-evoked myogenic potentials (cVEMP)	Mainly examination of saccular function	Non-invasive, is well tolerated, quite easy to perform	Interpretation of the findings is heterogeneous; different normative and pathological values recommended; the function of the vertical canals is also partially tested
Ocular vestibular-evoked myogenic potentials (oVEMP)	Mainly examination of utricular function	Non-invasive, is well tolerated, easy to perform	Similar to cVEMP
Subjective visual verticality (SVV)	Examination of an acute vestibular tone imbalance of the graviceptive pathways from the otolith organs (mainly utricle) and vertical semicircular canals	Non-invasive, is well tolerated, easy to perform, e.g., with the bucket test	Will be normalized during central compensation despite a persisting deficit; thus, deviation indicates an acute or not compensated lesion
Ocular motor system			
Video-oculography (VOG)	Measurement range ± 40° horizontally and ± 20° vertically, resolution of 0.1–1°; allows the recording of nystagmus, smooth pursuit, saccades, gaze-holding function, optokinetic nystagmus, suppression of the VOR	Non-invasive, well tolerated, combined with caloric testing and the head impulse test to determine the function of the VOR; nowadays widely used	Only possible with open eyes, artifacts possible: 3D analysis more complicated and expensive
Magnetic-coil technique by lens	Measurement range horizontal ±40°, vertical ±40°, resolution of 0.02°	Best resolution of horizontal, vertical, and torsional movements (research); can be combined with head impulse test if angular head velocity is also measured	Semi-invasive, unpleasant, expensive, only with cooperative patients, maximum of 30 min, local anesthesia necessary

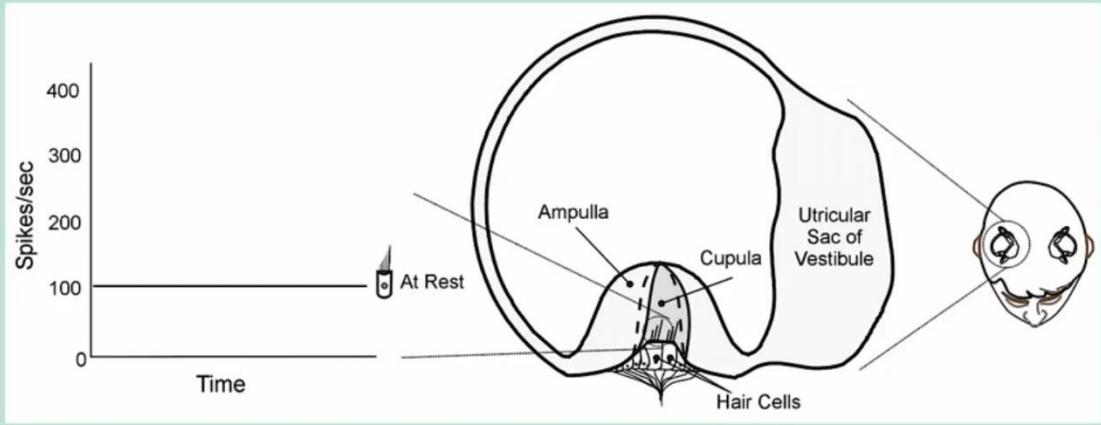

VOR Gain
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Head Impulse
Natural Head Movements
Active Daily Life Head Movements
Rotational Testing
Extended Rotational Testing
Caloric Testing
0.001
0.01
0.1
1.0
10.0
100.0
Frequency, Hz
VOR Phase
-90
-60
-30
0
30
60
90

4.1.1 Video Head Impulse Test

- Overt saccade
- Covert saccade
- VOR gain

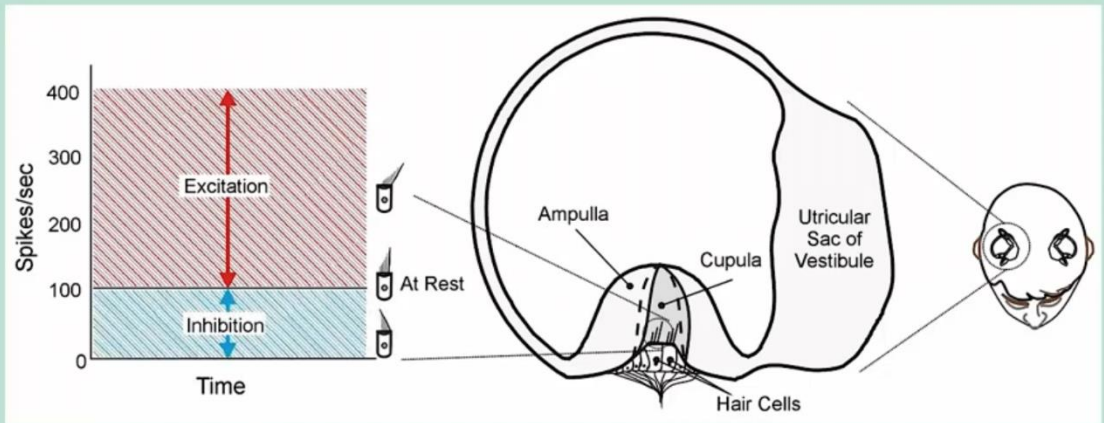


Head Impulse Test – *Mechanism*



- There is an asymmetry between excitatory and inhibitory neural responses of each semicircular canal (greater dynamic range for excitation)
  - Excitation from tonic level of ~100 up to a maximum of ~400 spikes/sec
  - Inhibition from tonic level of ~100 down to a minimum of 0 spikes/sec

Head Impulse Test – *Mechanism*



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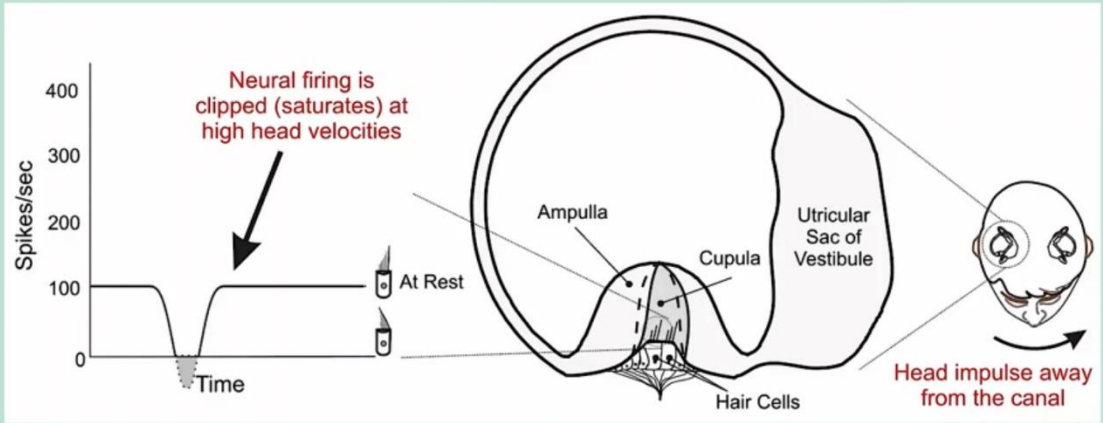
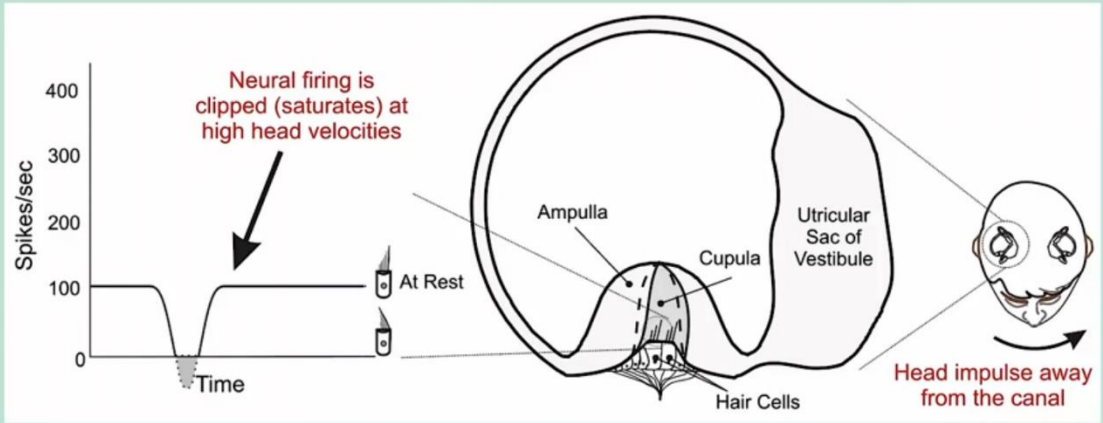
Head Impulse Test – *Changes in Neural Firing*



- Head impulses toward the canal cause excitation from that canal
  - Changes in the neural firing are proportional to the head velocity
- Head impulses away from the canal cause inhibition from that canal
  - Neural firing is clipped (saturates) at 0 spikes/sec and the canal does not provide an accurate measure of head velocity

Head Impulse Test – *Changes in Neural Firing*



- Head impulses toward the canal cause excitation from that canal
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- Head impulses away from the canal cause inhibition from that canal
  - Neural firing is clipped (saturates) at 0 spikes/sec and the canal does not provide an accurate measure of head velocity

- For the calculation of the VOR gain, different algorithms are used; e.g., the angular eye velocity is divided by the angular head velocity at 60 ms or the area under the curve of the eye angular velocity is divided by head angular velocity. bi
- VOR > 0.8 normal
  < 0.7 unilateral peripheral vestibular deficit

  bil VOR:
  0.8~0.6 presbyvestibulopathy
  < 0.6 bilateral vestibulopathy

4.1.2 Caloric Testing

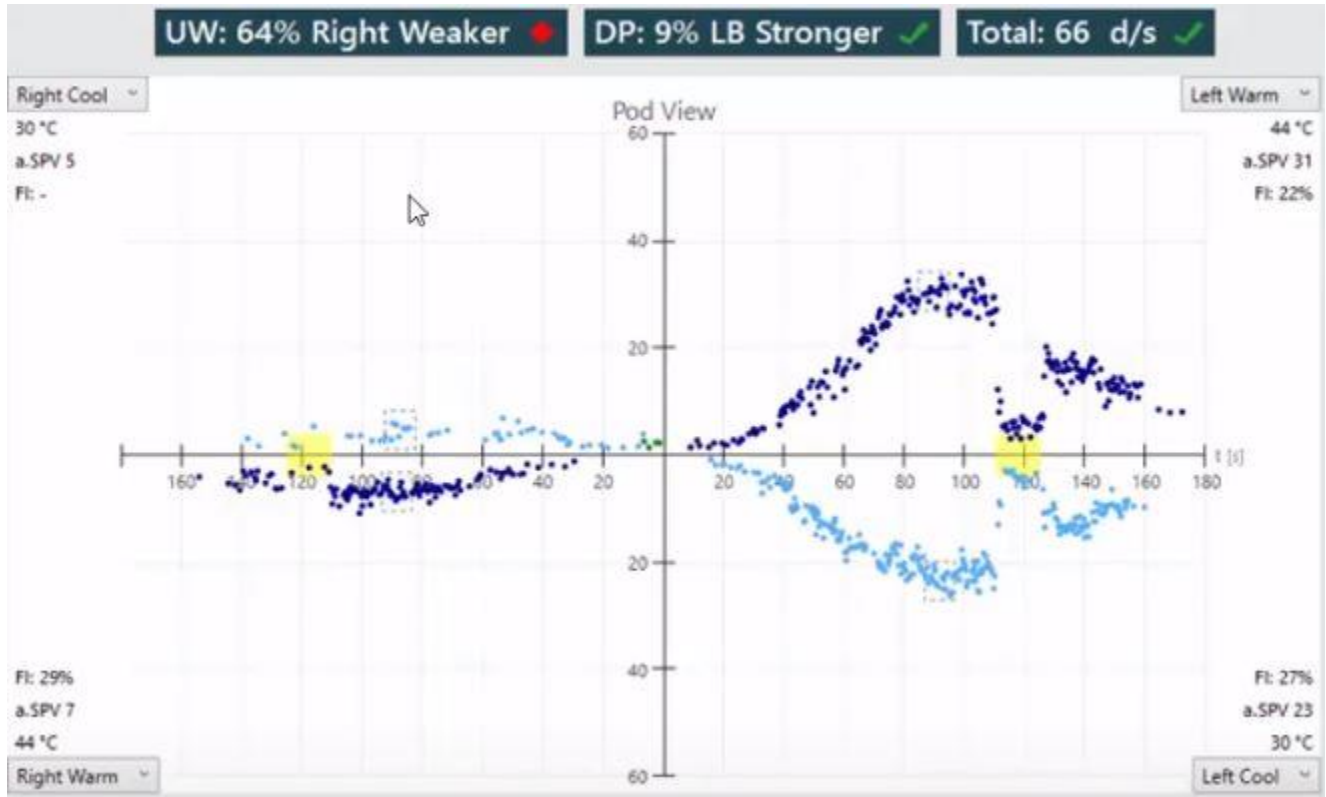
- the vestibular paresis formula

$$[((R\,30^{\circ} + R\,44^{\circ}) - (L\,30^{\circ} + L\,44^{\circ})]/[(R\,30^{\circ} + R\,44^{\circ} + L\,30^{\circ} + L\,44^{\circ}))] \times 100$$

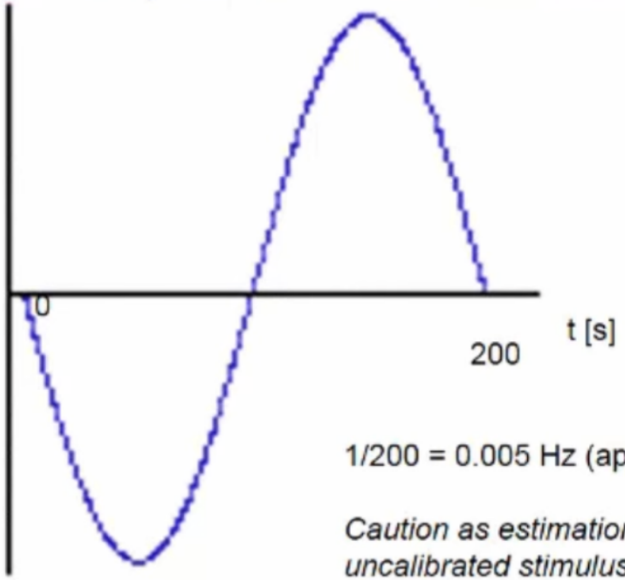
- The directional preponderance formula

$$[((R\,33^{\circ} + L\,44^{\circ}) - (R\,44^{\circ} + L\,30^{\circ})]/[(R\,30^{\circ} + L\,44^{\circ} + R\,44^{\circ} + L\,30^{\circ}))] \times 100$$

- mean peak slow phase velocity (mPSPV) $<3^{\circ} - 6^{\circ}/s$ => pathological for a unilateral peripheral deficit
- the sum of the mPSPV for warm and cold irrigation is assumed to be $<6^{\circ}/s$ on each side => bilateral vestibulopathy (BVP)
- An asymmetry according to Jongkees' vestibular paresis formula of up to 19% is normal, a side difference of >20–25% is pathologic.


UW: 64% Right Weaker
DP: 9% LB Stronger
Total: 66 d/s
Right Cool
30 °C
a.SPV 5
FI: -
Pod View
Left Warm
44 °C
a.SPV 31
FI: 22%
FI: 29%
a.SPV 7
44 °C
Right Warm
FI: 27%
a.SPV 23
30 °C
Left Cool
60
40
20
20
40
60
160
120
40
20
20
60
80
100
140
160
180
t [s]

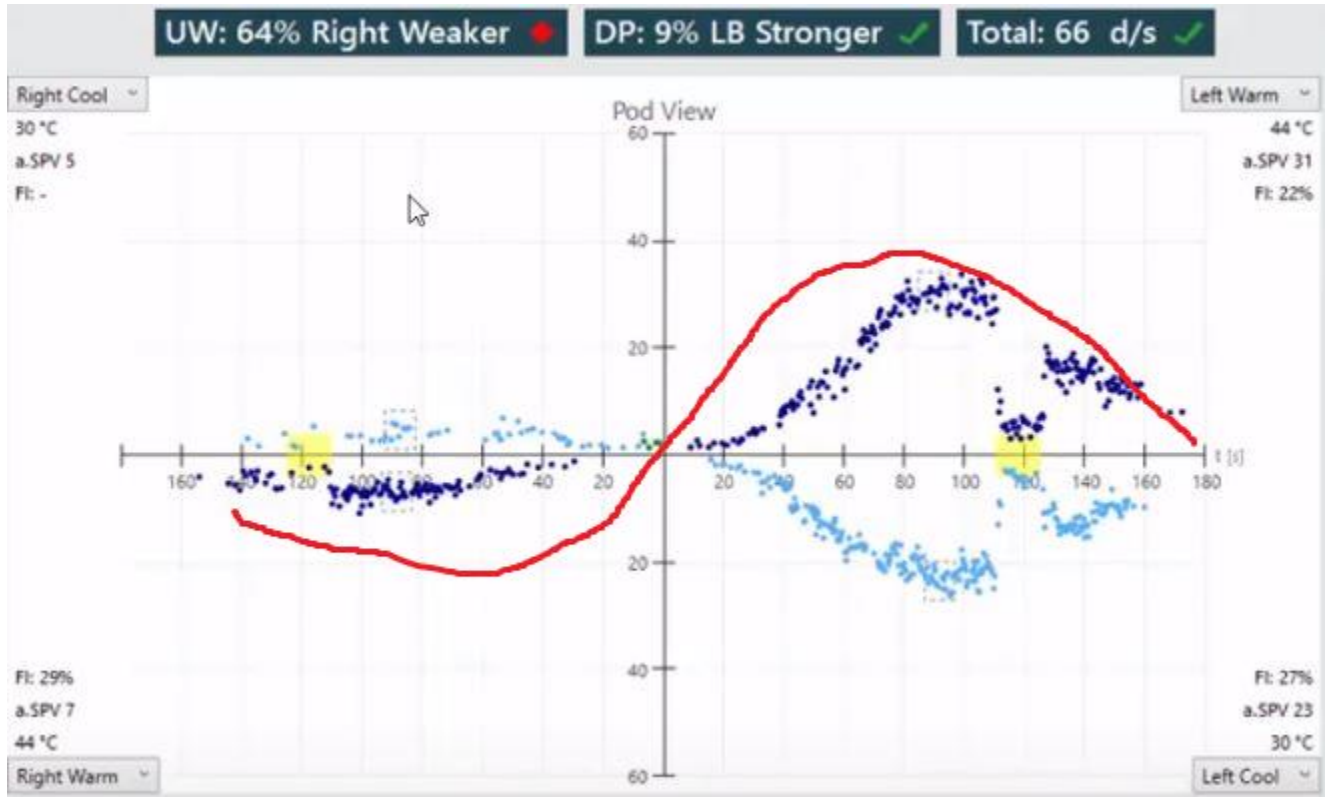
Frequency response of the caloric



1/200 = 0.005 Hz (approx.)

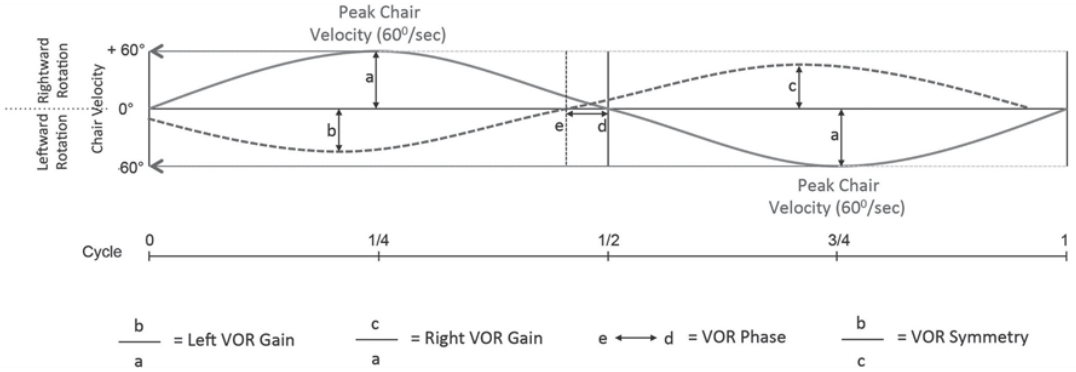
Caution as estimation based on uncalibrated stimulus

Caloric responses may typically last 120 seconds, producing a frequency of 1/240 = 0.004 Hz

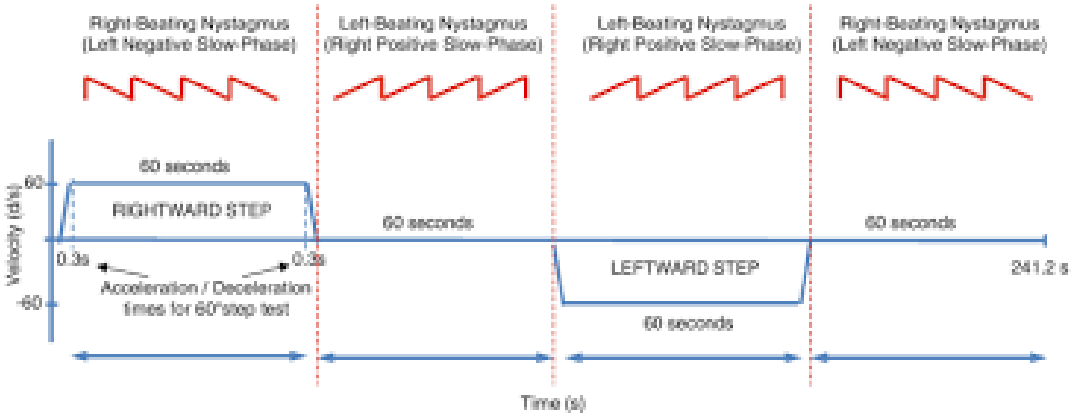

UW: 64% Right Weaker
DP: 9% LB Stronger
Total: 66 d/s
Right Cool
30 °C
a.SPV 5
Fl: -
Pod View
Left Warm
44 °C
a.SPV 31
Fl: 22%
Fl: 29%
a.SPV 7
44 °C
Right Warm
Fl: 27%
a.SPV 23
30 °C
Left Cool
60
40
20
20
40
60
160
120
40
20
20
60
80
100
140
160
180
t [s]

4.1.3 Rotatory Chair Testing

- Sinusoidal harmonic acceleration test (SHAT)
  VOR: 0.005~0.64 Hz

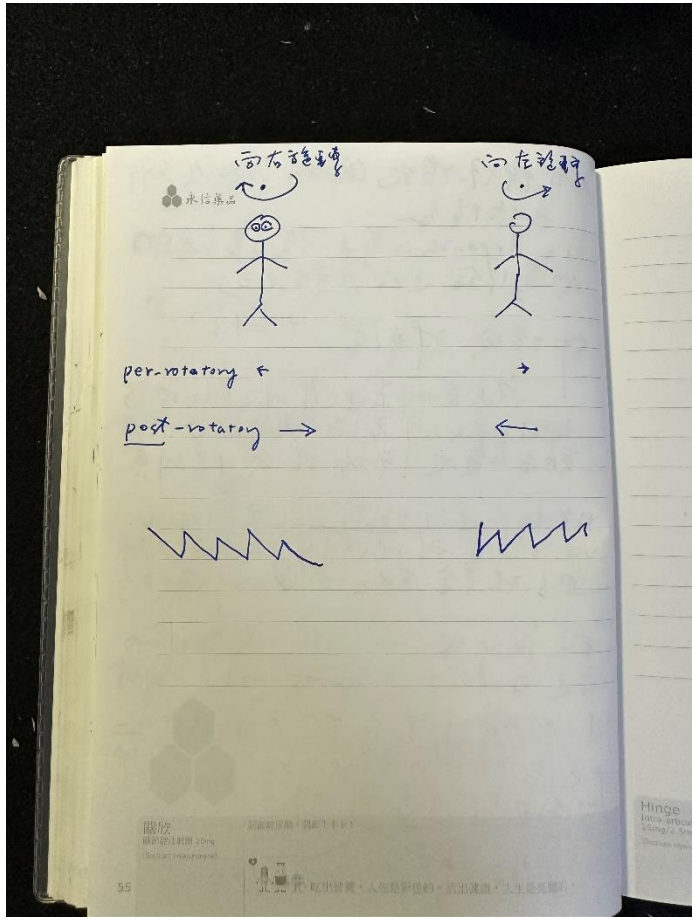


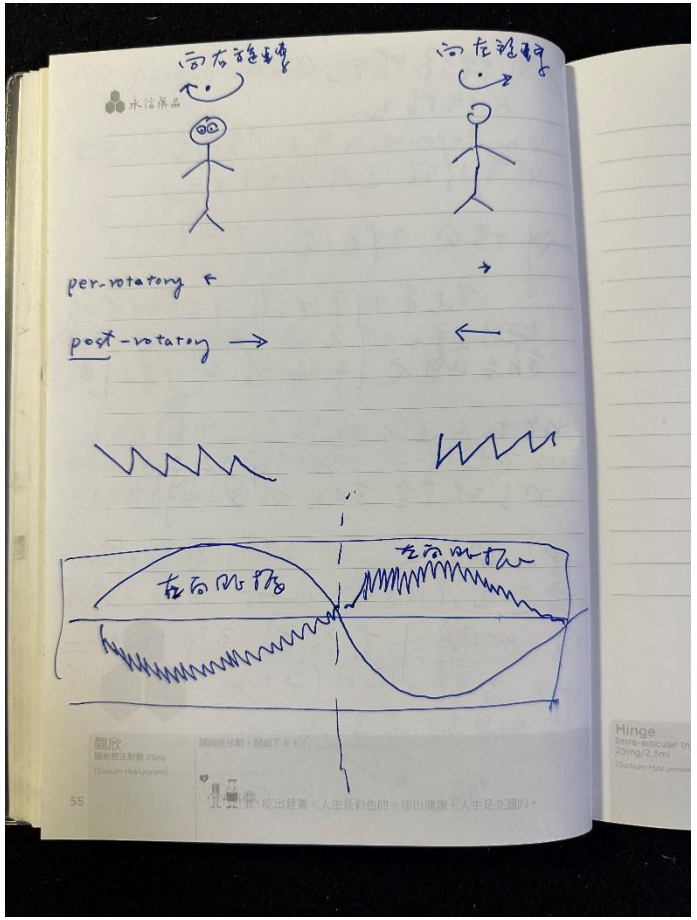
- Veloity step test (VST)
  constant rotation with 100°/s and subsequent deceleration with 200°/s



- For the diagnosis of BVP,a reduced horizontal angular VOR gain ≤0.1 upon sinusoidal stimulation on a rotatory chair (0.1 Hz, Vmax = 50°/sec) and a phase lead ≥ 15 degrees (time constant ≤ 6 sec) is proposed.
- the clinical relevance of the rotatory chair examination has decreased considerably over the last years, in particular since VOR function can be reliably examined by the video-HIT, and is therefore only indicated in exceptional cases.

Incorrect concept on 3/27





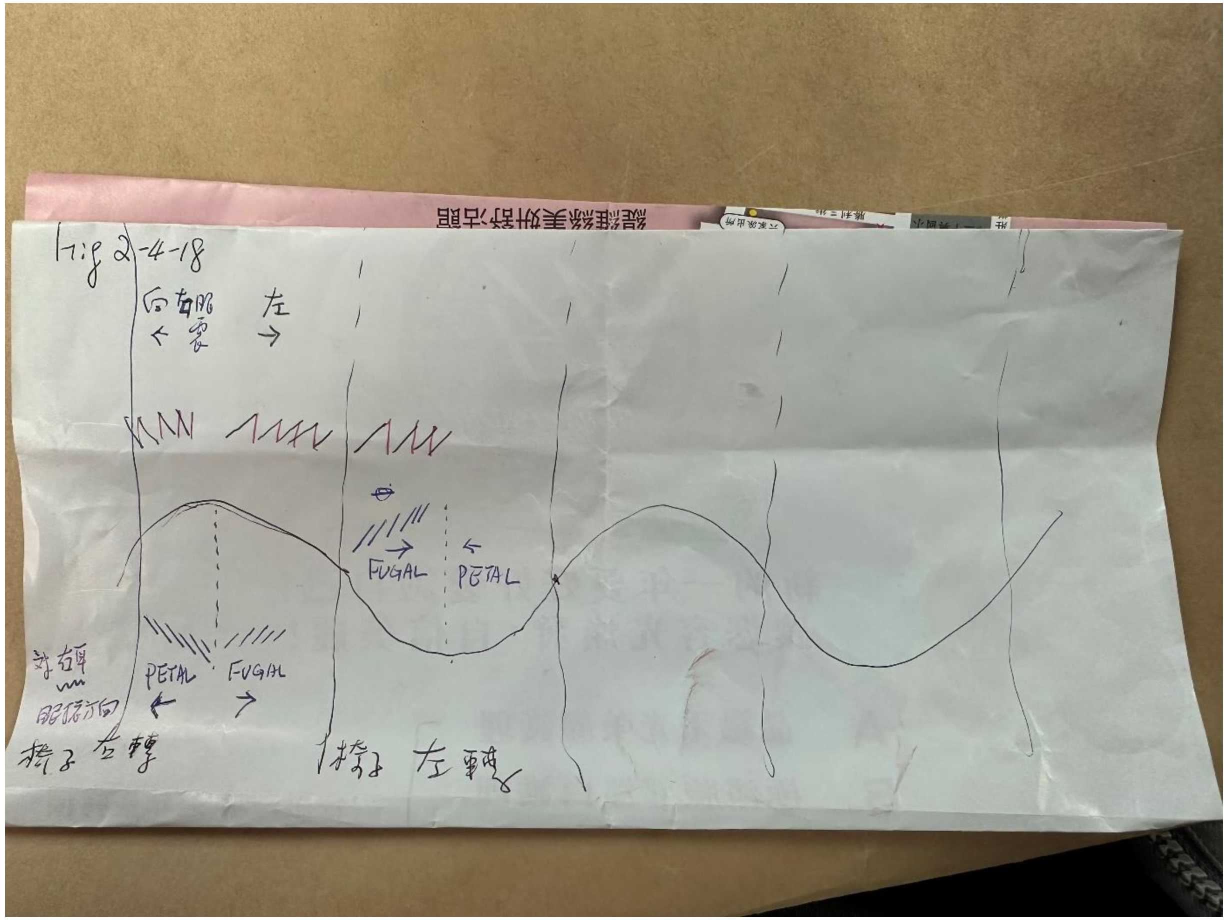
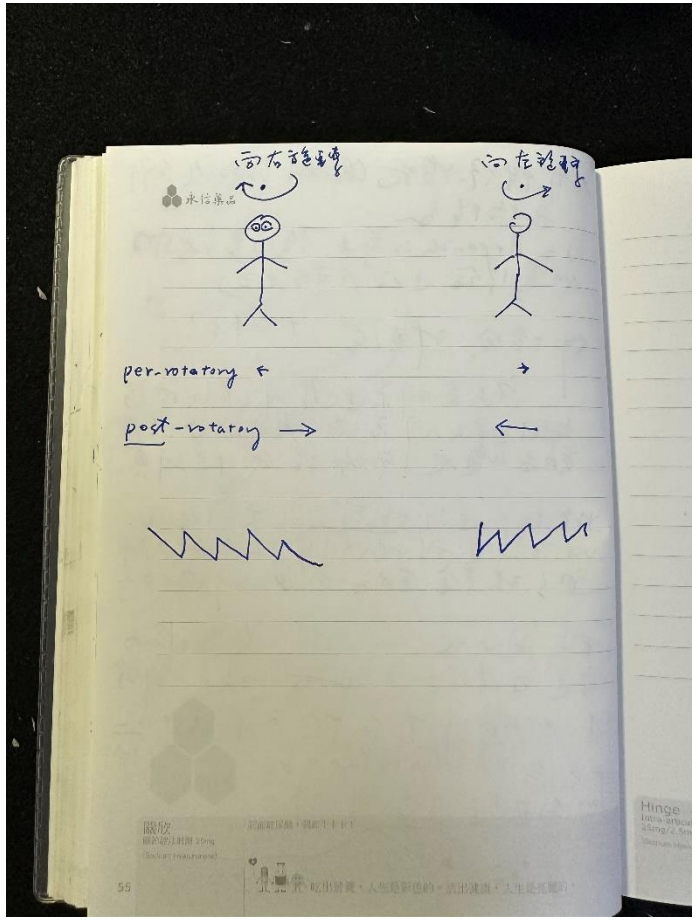


Fig 2-4-18
左
PETAL
FUGAL
FUGAL
PETAL
椅子 左轉

Phase lead
Phase lag



加到其峰速，然后减速到 0° /s。软件程序在记录的眼震中删除 VOR 的快相成分，只剩下慢相前庭成分。测量每个慢相的程度，并绘制出与转椅振荡相关的曲线。因为前庭眼震的慢相速度与转椅旋转方向相反，眼震的强度随转椅旋转的加速和减速而增加和减少，所以合成的眼震速度和转椅速度数据总是表现为相反的（或镜像的）正弦曲线，即彼此相差 180°。通过这一图形应用各种算法得到前庭反应的增益、相位和对称性（图 2-4-17 ~ 图 2-4-19）。

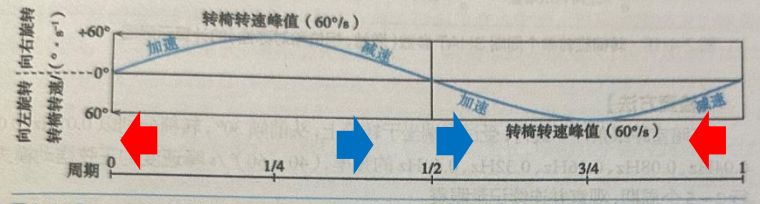


图 2-4-17 一个旋转周期的向右和向左旋转的转椅转速曲线
转椅速度以预定的目标速度达到峰值（在本例中为 60° /s）。

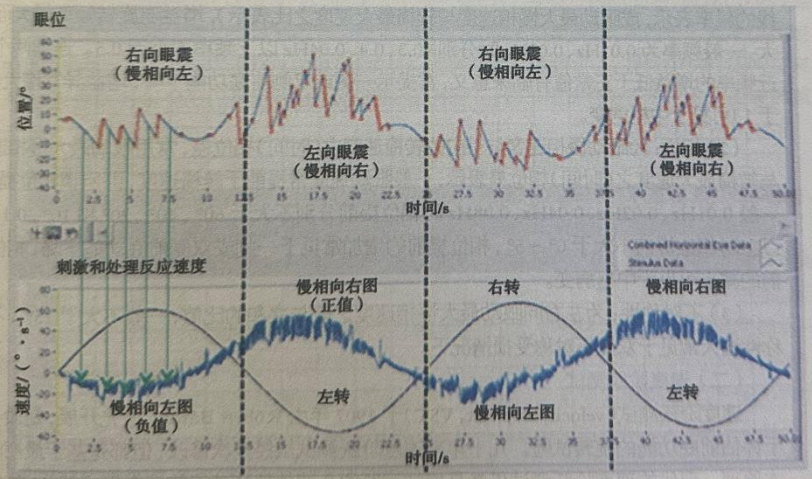
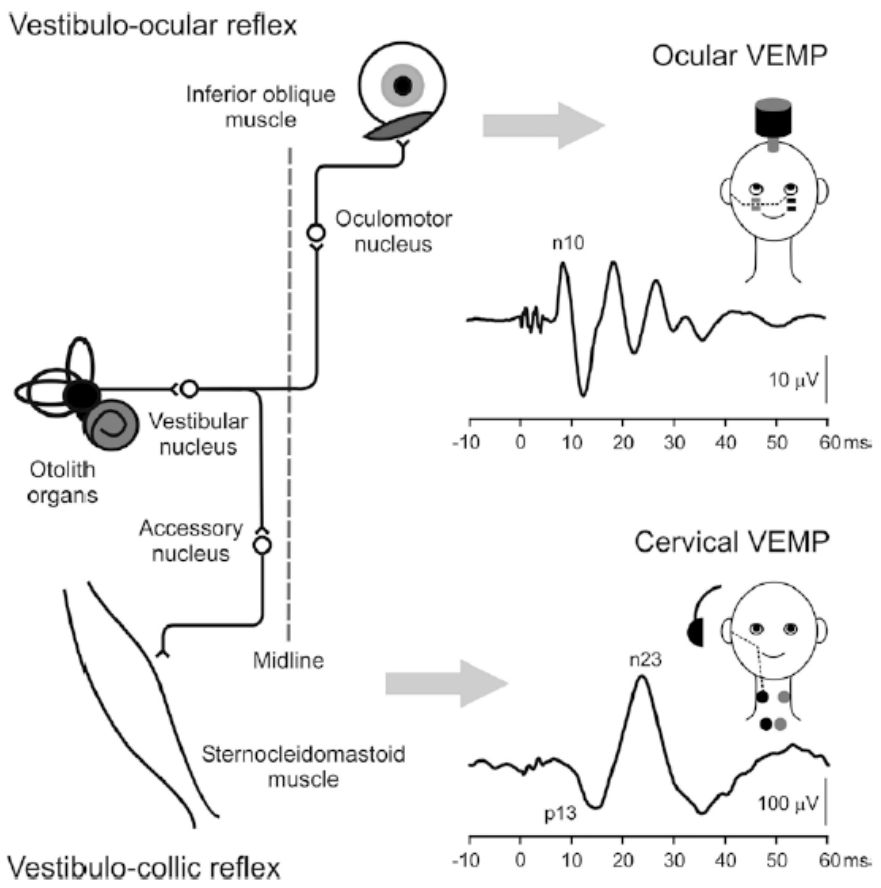


图 2-4-18 SHAT 参数分析举例
上图. 去除前庭性眼震的快相成分（如橙色所示）；下图. 用前庭性眼震的慢相成分绘出旋转周期的慢相眼速图（下图的绿色箭头）。

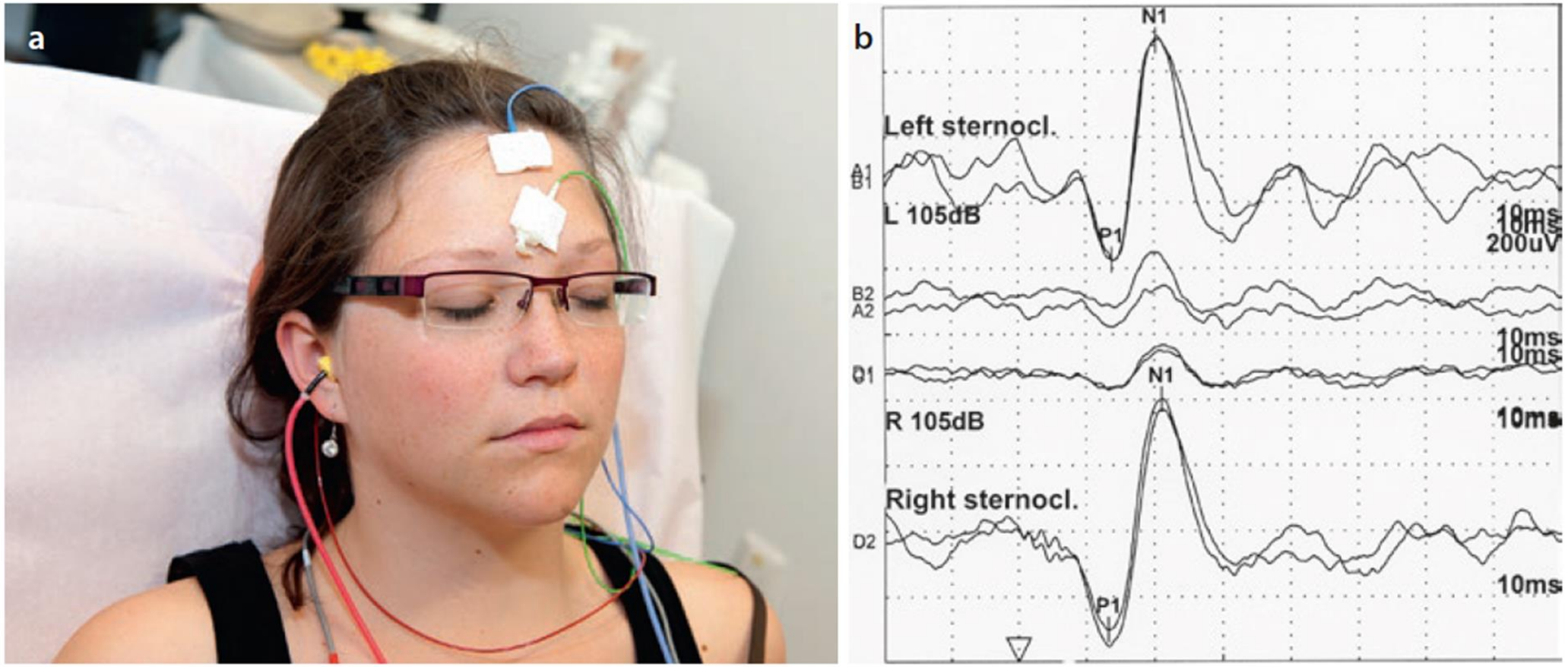
4.1.4 Vestibular-Evoked Myogenic Potentials (VEMP)

- Cervical VEMP (cVEMP) are used to evaluate the function of the *ipsilateral* saccule
  ocular VEMP (oVEMP) that of the *contralateral* utricle
- in ACS-VEMP, the sensitivity of the otolith organs and not the cochlea to sounds is measured. In contrast to the ACS stimuli, BCV stimuli can be applied independent of middle ear function.



- the amplitudes of the oVEMP areincreased and the threshold of the cVEMP is decreased in superior canal dehiscence syndrome.
- oVEMP can be performed more easily than cVEMP and do not depend on a threshold.
- oVEMP are evidently more sensitive and specific than cVEMP for the diagnosis of superior canal dehiscence syndrome and other third mobile windows.

The reflex is most often induced by a 500-Hz pure tone with a duration of 2 ms and up to 130 dB peak sound pressure level. Criteria for the evaluation of cVEMP are the presence of P13 and N23 waves and their amplitudes; the latency is less important.



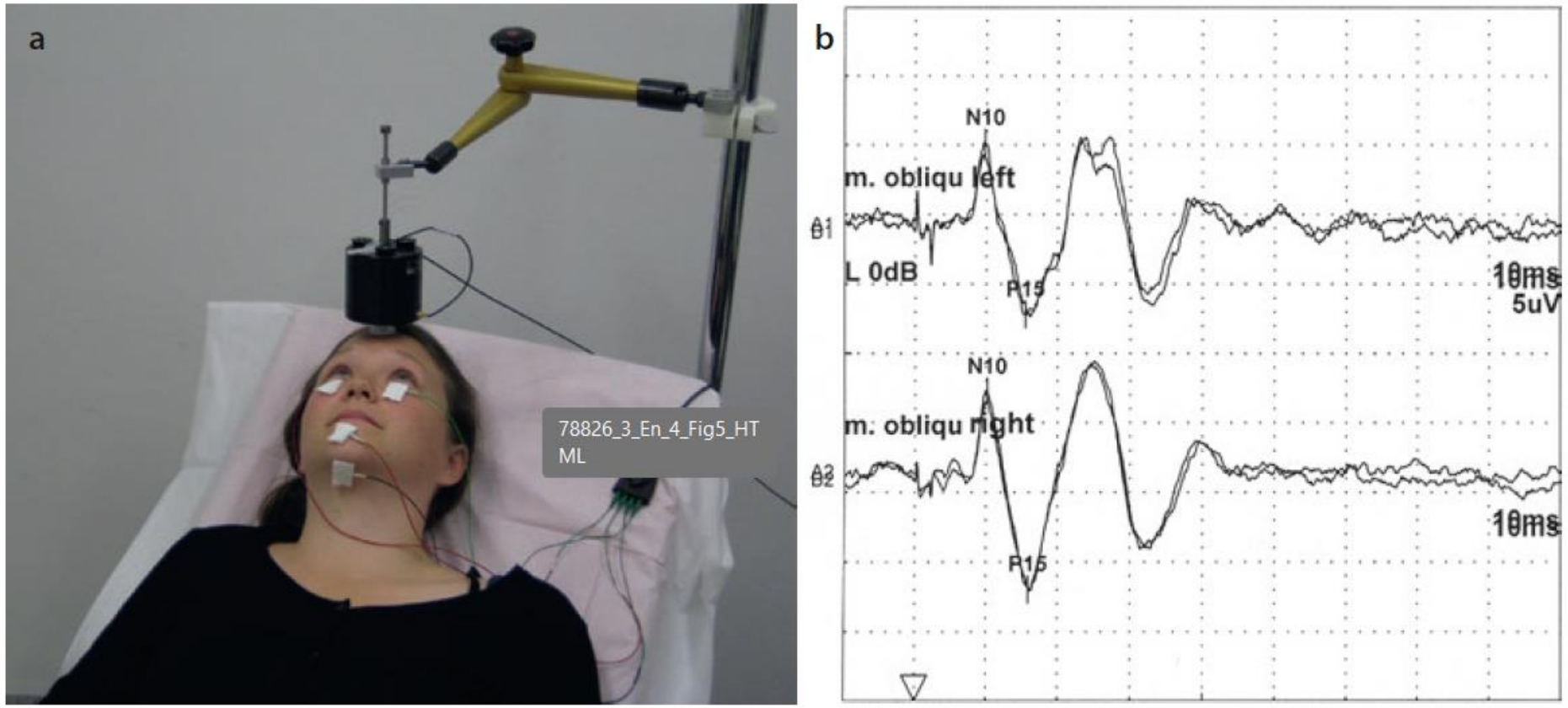
- canal dehiscence syndrome:
  the threshold for cVEMP is reduced, i.e., even sounds with low decibel values can induce waves with increased amplitudes.
  a stimulation frequency of 2000 Hz; this has a specificity of almost 100% and a sensitivity of 92%.
- Acute unilateral vestibulopathy/vestibular neuritis:
  2/3 of the patients, cVEMP are normal (by sparing of the inferior part of the vestibular nerve).

- Bilateral vestibulopathy:
  cVEMP are reduced or absent in only a small number of patients with bilateral vestibulopathy. It is so far not known why otolith function is evidently more preserved than semicircular canal function in bilateral vestibulopathy.
- Meniere's disease:
  a higher asymmetry ratio for cVEMP than for oVEMP amplitudes.
  (more common saccular than utricular dysfunction in MD and a more permanent loss of otolith function in MD versus VM.)

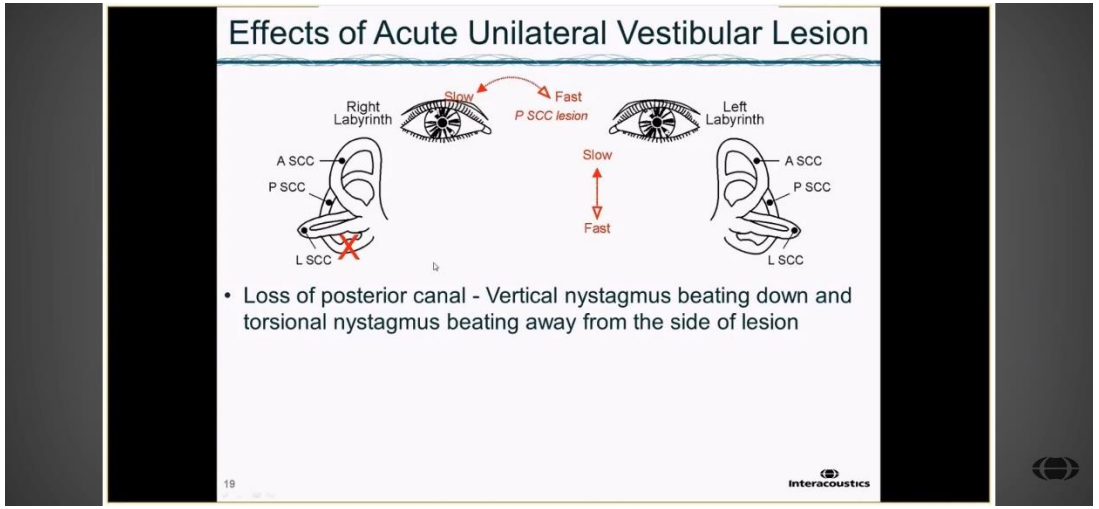
4.1.4 Ocular Vestibular-Evoked Myogenic Potentials (oVEMP)

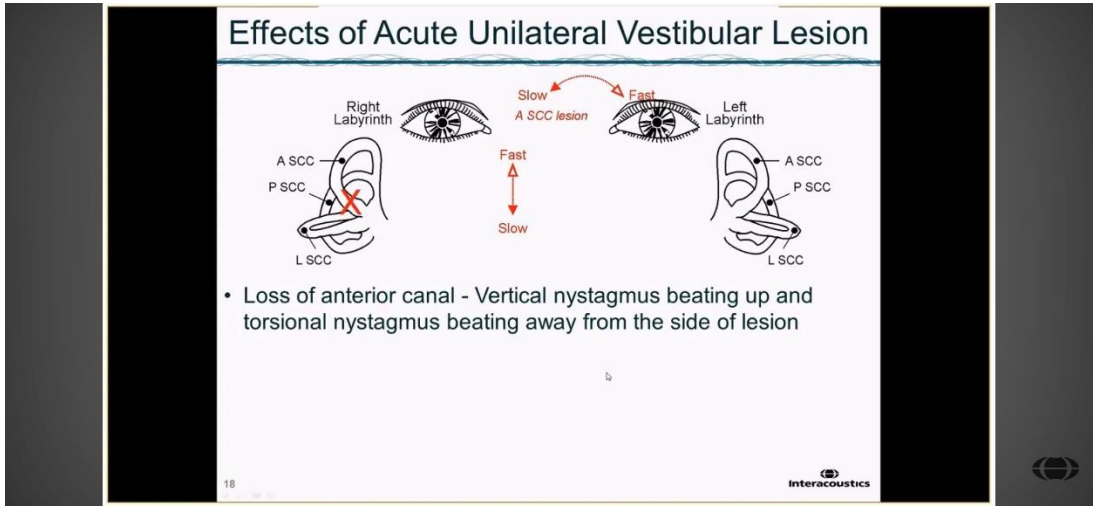
- Criteria for the evaluation of oVEMP are the presence or absence of N10 and P15 waves and their amplitude. Increased latencies were observed in neurological disorders, e.g., multiple sclerosis, with an involvement of the brainstem. No waves or a significant asymmetry of the amplitudes is considered pathological, although there are so far no normative values.
- A peak-to-peak amplitude of the oVEMP of more than 16.7 µV (ACS, 500 Hz, 125 dB SPL) has a sensitivity of 100% and a specificity of 89% for superior canal dehiscence syndrome.

a minishaker (boneconducted vibration) in the middle of the forehead at the hairline (Fz). Criteria for the evaluation are the presence of these waves and their amplitudes; the latency is less important.

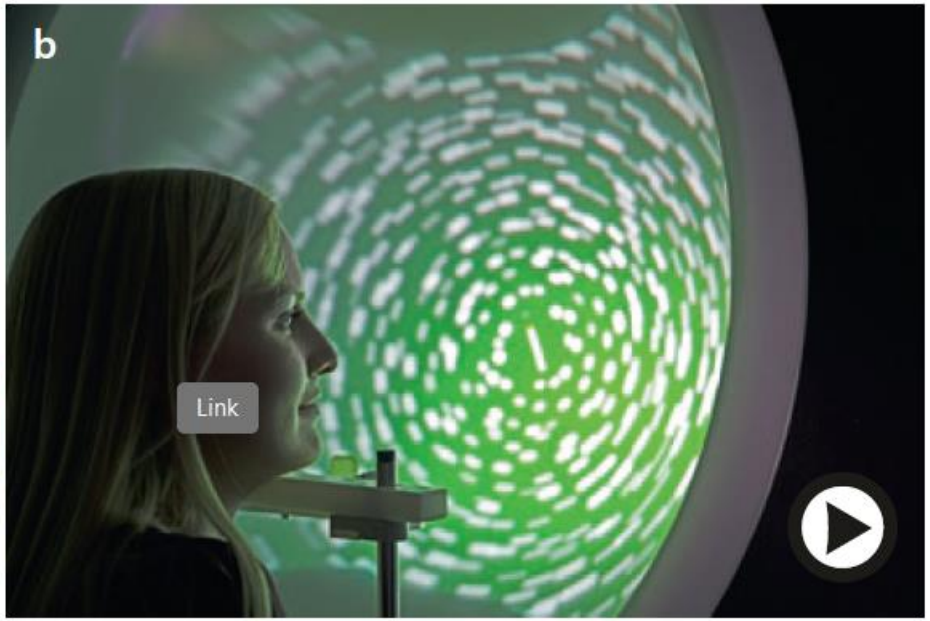


4.3 hypo/hyper function of canals vs. excitatory/inhibitory stimulation





4.4 Neuro-Orthoptic and Psychophysical Tests



- Cover tests, to detect vertical deviation (skew deviation)
- Psychophysical measurement of the subjective visual vertical (SVV), or with the simple bucket test to detect an acute or subacute imbalance of the labyrinths or graviceptive pathways and to differentiate a monocular infranuclear lesion (e.g., third or fourth nerve) from a vestibular lesion.
  A deviation of the SVV under binocular as well as monocular viewing conditions indicates a vestibular lesion, whereas a third or fourth nerve palsy causes a deviation of the affected eye only.

Puzzle?

- 生理性眼偏斜反應是人類或動物用以代償姿態變化時，穩定對前方物體的注視。不會有roll方位頭部轉動的外側性眼球(laterally placedeyes) 動物，就會以偏斜視代償roll 方位的身體傾斜，以眼球旋轉代償pitch 方位傾斜，如魚類；
- 在前額眼位(frontal-eyed) 的動物，則以眼球旋轉及頭位傾斜代償roll 方位傾斜，頭位傾斜可彌補眼球旋轉的不足，亦可完全代償姿態傾斜，例如鳥類，在軀體劇烈的roll方位傾斜變化時，即使沒有視覺協助下，還是會保持頭部在重力垂直的方向，並不需要眼球的逆向旋轉或偏斜視。

一側的橢圓囊受到刺激，或對側橢圓囊受到抑制時，便會刺激同側上直肌、內直肌、上斜肌，及對側下斜肌、外直肌、下直肌的收縮，並抑制同側下直肌、外直肌、下斜肌，及對側上斜肌、內直肌、上直肌的收縮，如此便可造成該側眼內旋高斜視(ipsilateral hypertropia with intortion) 及對側眼外旋低斜視(contralateral hypotroia with extortion).

表 1. 半規管及橢圓囊耳石器對於眼外肌的影響

	橢圓囊			
	刺激		抑制	
	同側	對側	同側	對側
前半規管	上直肌	下斜肌	下直肌	上斜肌
水平半規管	內直肌	外直肌	外直肌	內直肌
後半規管	上斜肌	下直肌	下斜肌	上直肌

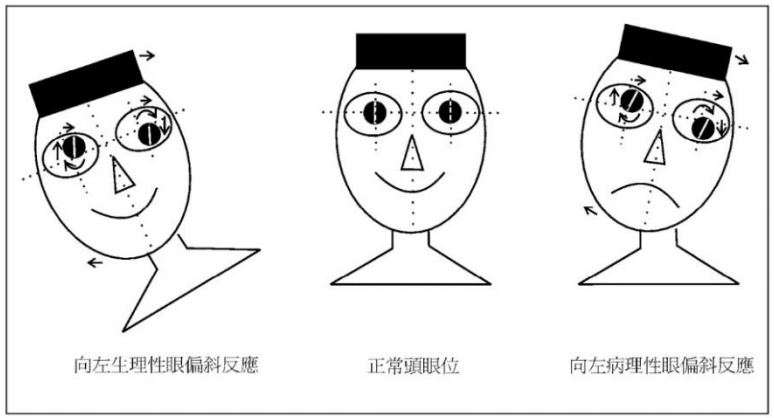
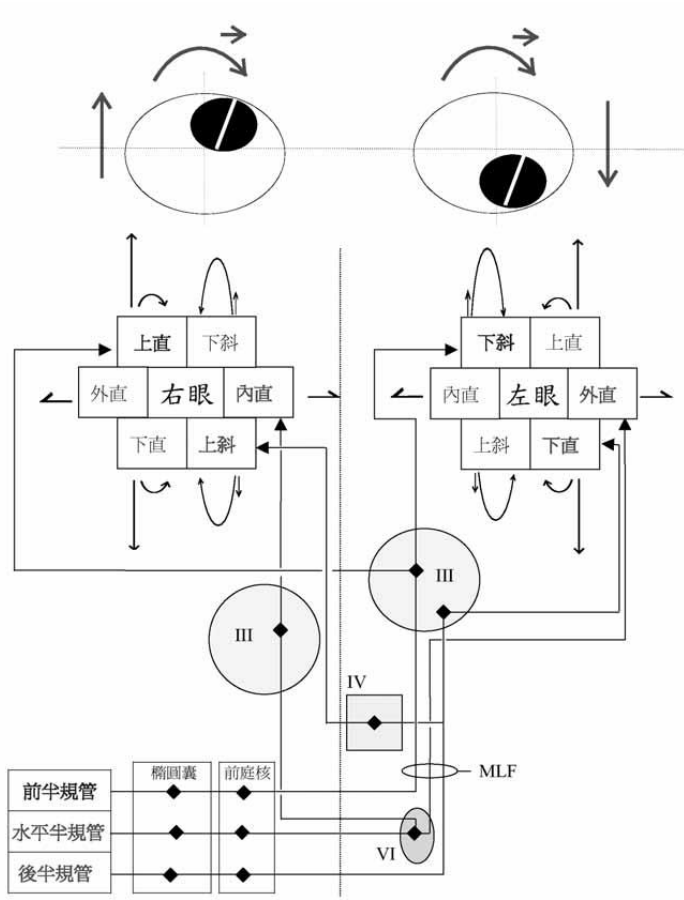
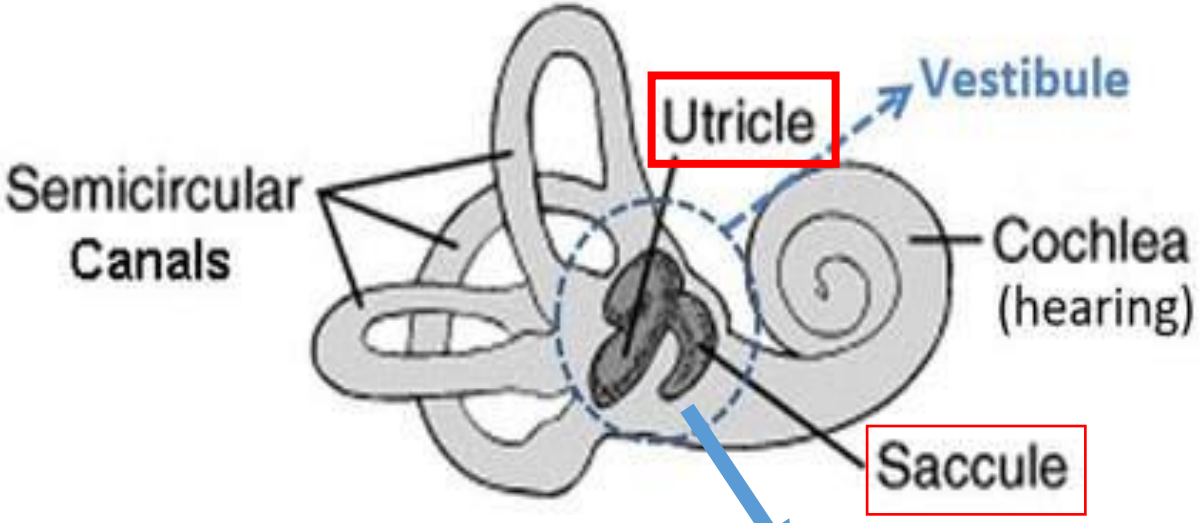
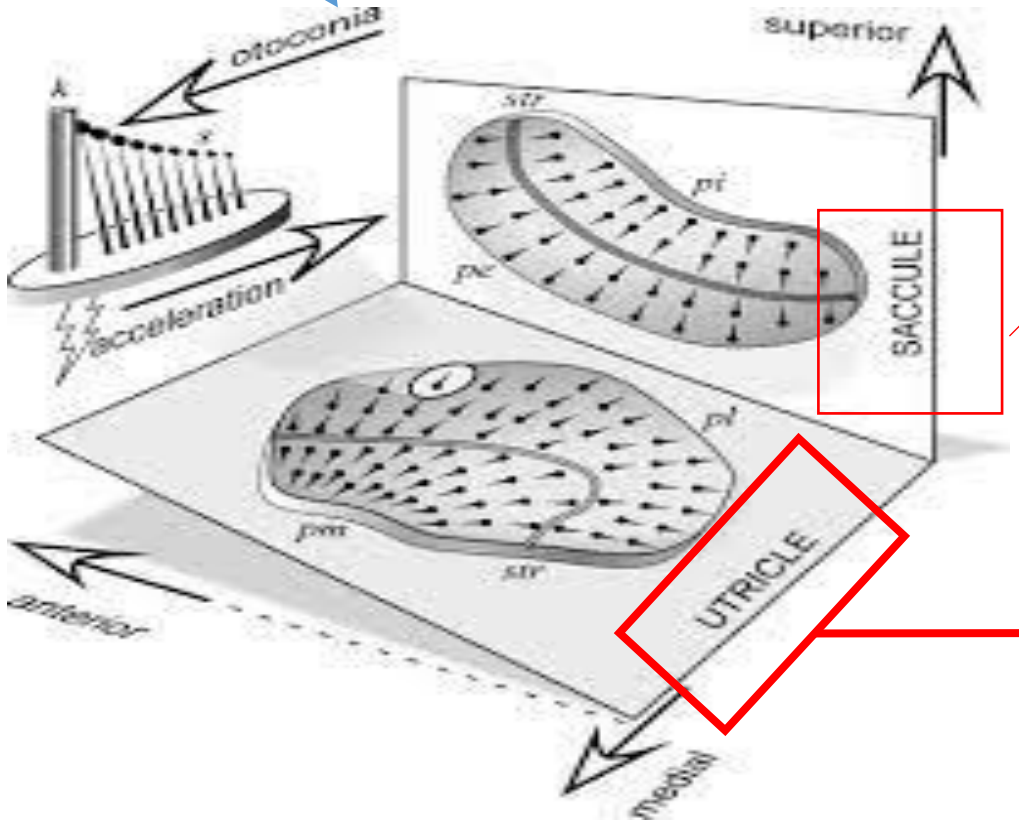


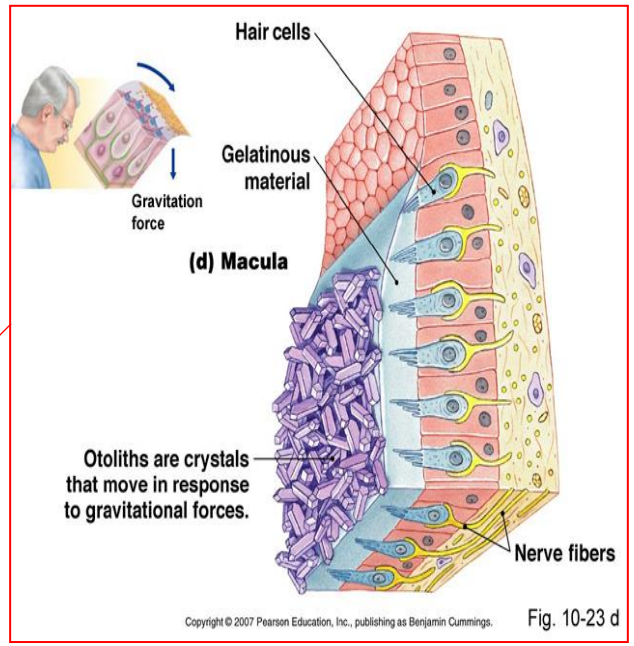
圖 1. 中間：在一個重力方向向下之正常人頭眼位置。左圖：正常人向右傾斜時，右側橢圓囊耳石器受到刺激，便會出現頭向左傾，兩側眼球均向左旋轉 (逆向旋轉)、左眼低斜視及右眼高斜視的生理性眼偏斜反應，但是，不論是頭位偏斜和眼球旋轉，在正常情況下仍是無法完全代償姿態的傾斜。右圖：左側橢圓囊、前庭神經或前庭神經核，或右側中腦—間腦或小腦病變時的向左病理性眼偏斜反應。


上直
下斜
外直
右眼
内直
下直
上斜
下斜
上直
内直
左眼
外直
上斜
下直
III
III
IV
MLF
VI
前半規管
水平半規管
後半規管
橢圓嚢
前庭核

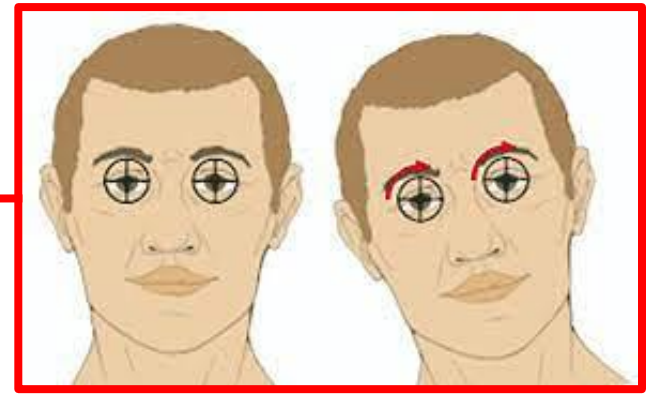




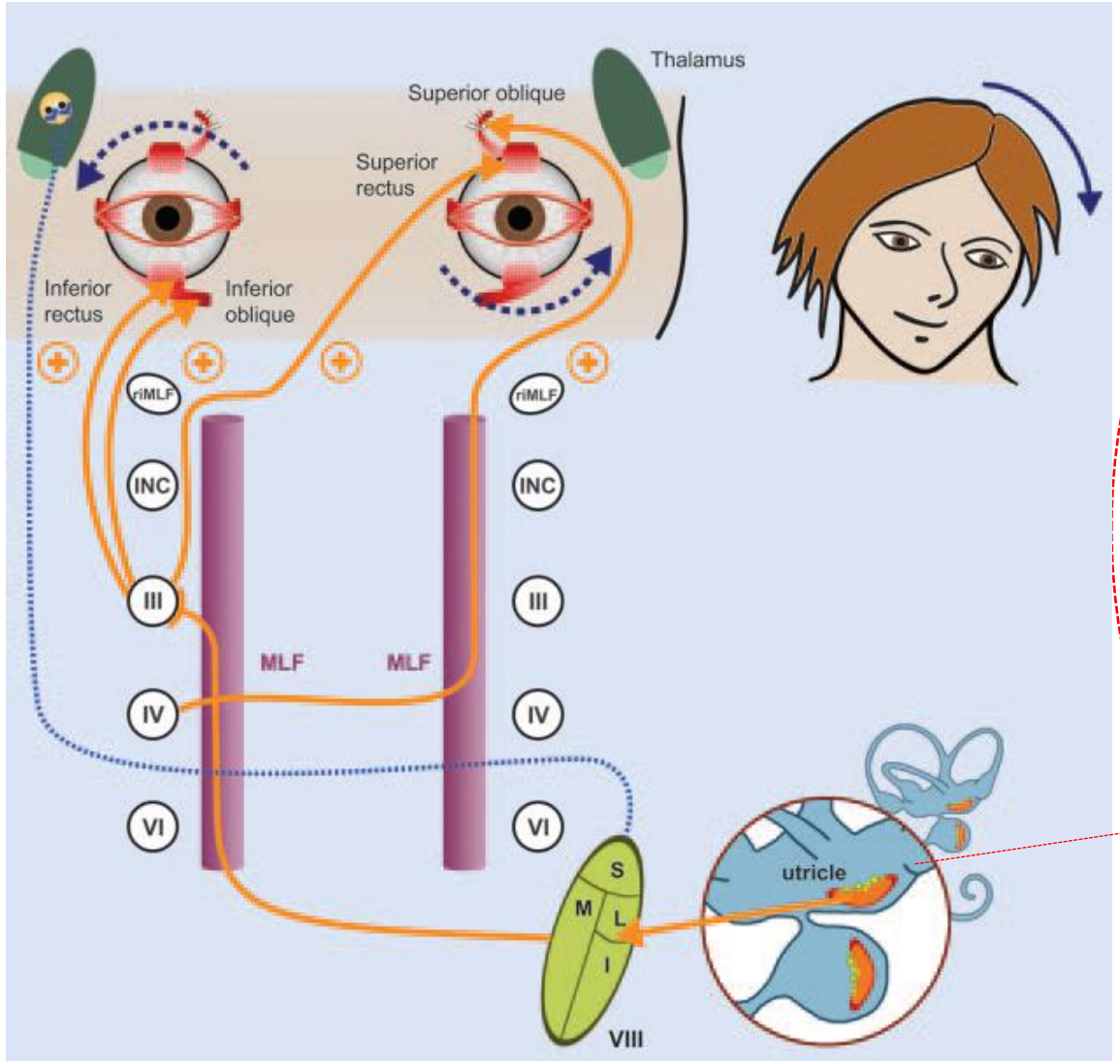
Pitch plane

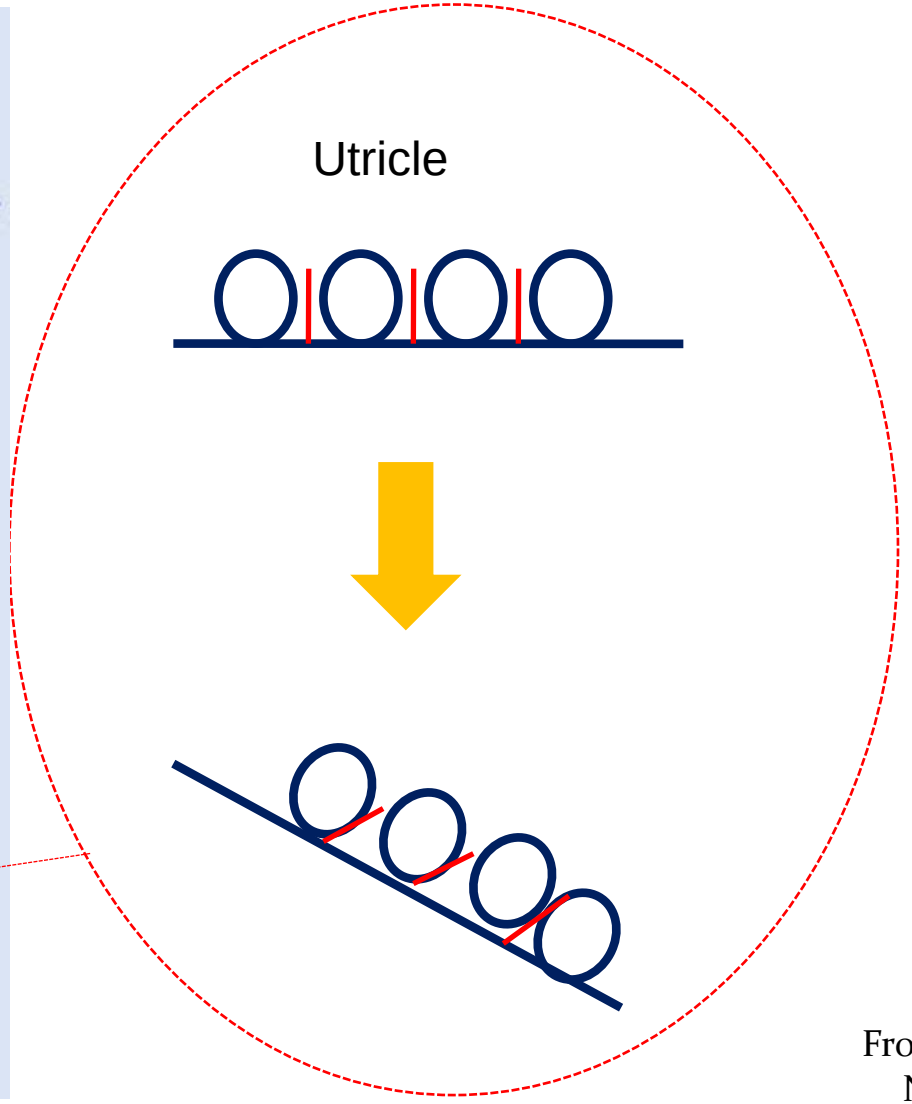


Roll plane



Utricular-Ocular Reflex and Vestibular Perception





Frohman TC, et al. Neurology 2008

Which one is correct?

验这三个床旁检查方法的简称头脉冲 - 眼震 - 眼偏斜试验（head impulse + nystagmus + test of skew，HINTS），HINTS 检查法可能在脑卒中伴眩晕疾病的诊断优于早期弥散加权磁共振检查。

【原理】

OTR 为双眼位于头部冠状位、视网膜中央凹的物种如人类所特有的；而眼位于头部两侧、无视网膜中央凹的动物则无 OTR 体征。正常人如果头部向一侧倾斜，比如头部向左倾斜（头部向左肩部倾斜），此时左侧椭圆囊兴奋，右侧椭圆囊抑制，左眼内旋，右眼外旋，以保持正确的主观垂直视觉，同时出现左眼向上运动，右眼向下运动，双眼在垂直方向相向运动，尽量使双眼在水平方向上保持同平面。前庭损害累及椭圆囊时，比如左侧椭圆囊损害，此时出现头向左侧倾斜（head tilt），左眼外旋、右眼内旋（ocular counter torsion），主观垂直视觉向左侧偏，同时出现左眼向下运动，右眼向上运动，双眼在垂直方向呈相反方向运动即反向偏斜（skew deviation），以上 4 个体征合称为 OTR。正常人头向左倾斜与左侧椭圆囊损害后虽然都表现为头向左倾斜，但双眼在扭转方向和垂直方向的运动是相反的，病理情况下会出现主观垂直偏斜，二者眼球运动差别见图 2-4-25。

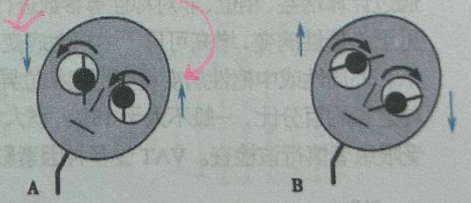


图 2-4-25 生理性头左倾斜与左侧椭圆囊损害后眼球运动差异比较示意图

A. 生理性头左倾斜，表现为左眼内旋、右眼外旋，左眼向上、右眼向下；B. 病理性头左倾斜，表现为左眼外旋、右眼内旋，左眼向下、右眼向上。

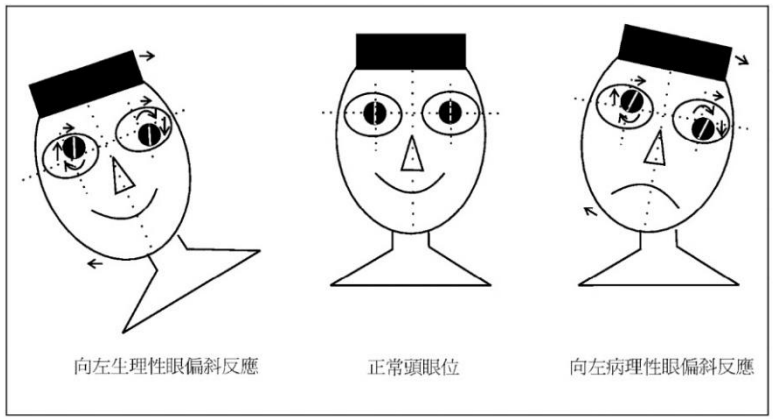
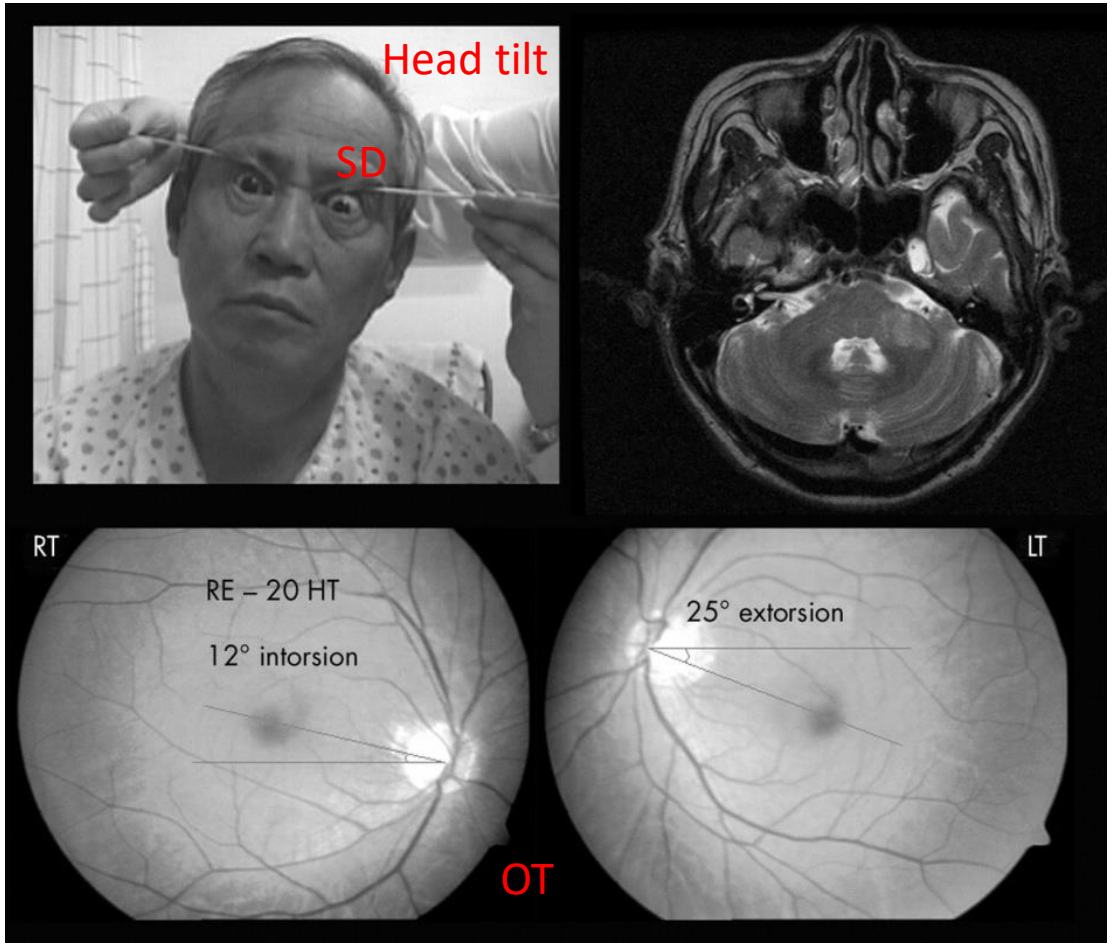


圖 1. 中間：在一個重力方向向下之正常人頭眼位置。左圖：正常人向右傾斜時，右側椭圓囊耳石器受到刺激，使會出現頭向左傾，兩側眼球均向左旋轉（逆向旋轉）、左眼低斜視及右眼高斜視的生理性眼偏斜反應，但是，不論是頭位偏斜和眼球旋轉，在正常情況下仍是無法完全代償姿態的傾斜。右圖：左側椭圓囊、前庭神經或前庭神經核，或右側中腦—間腦或小腦病變時的向左病理性眼偏斜反應。

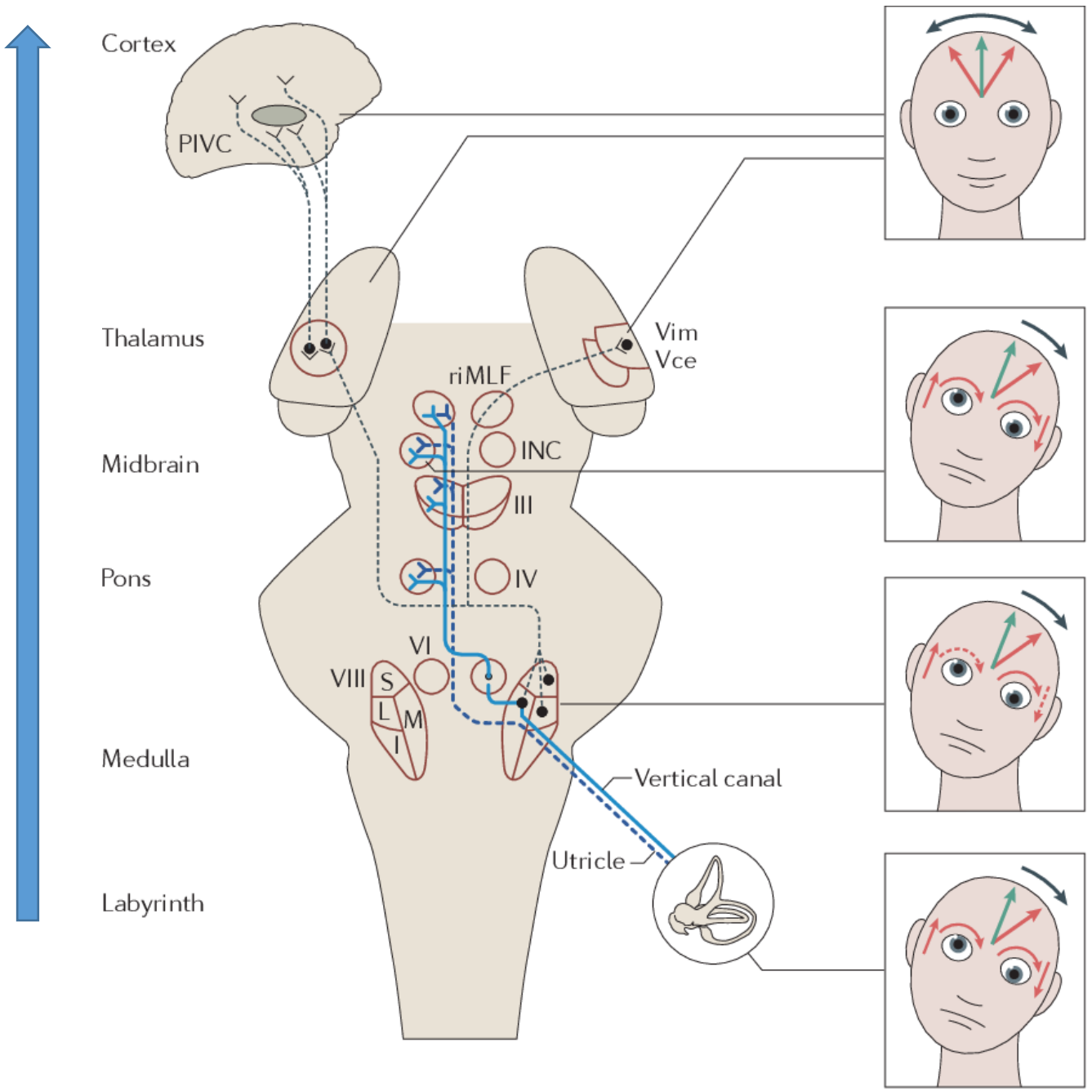
Ocular Tilt Reaction (OTR)

- Tilt of subjective visual vertical (SVV)
- Ocular torsion (OT)
- Skew deviation (SD)
- Head tilt

SVV



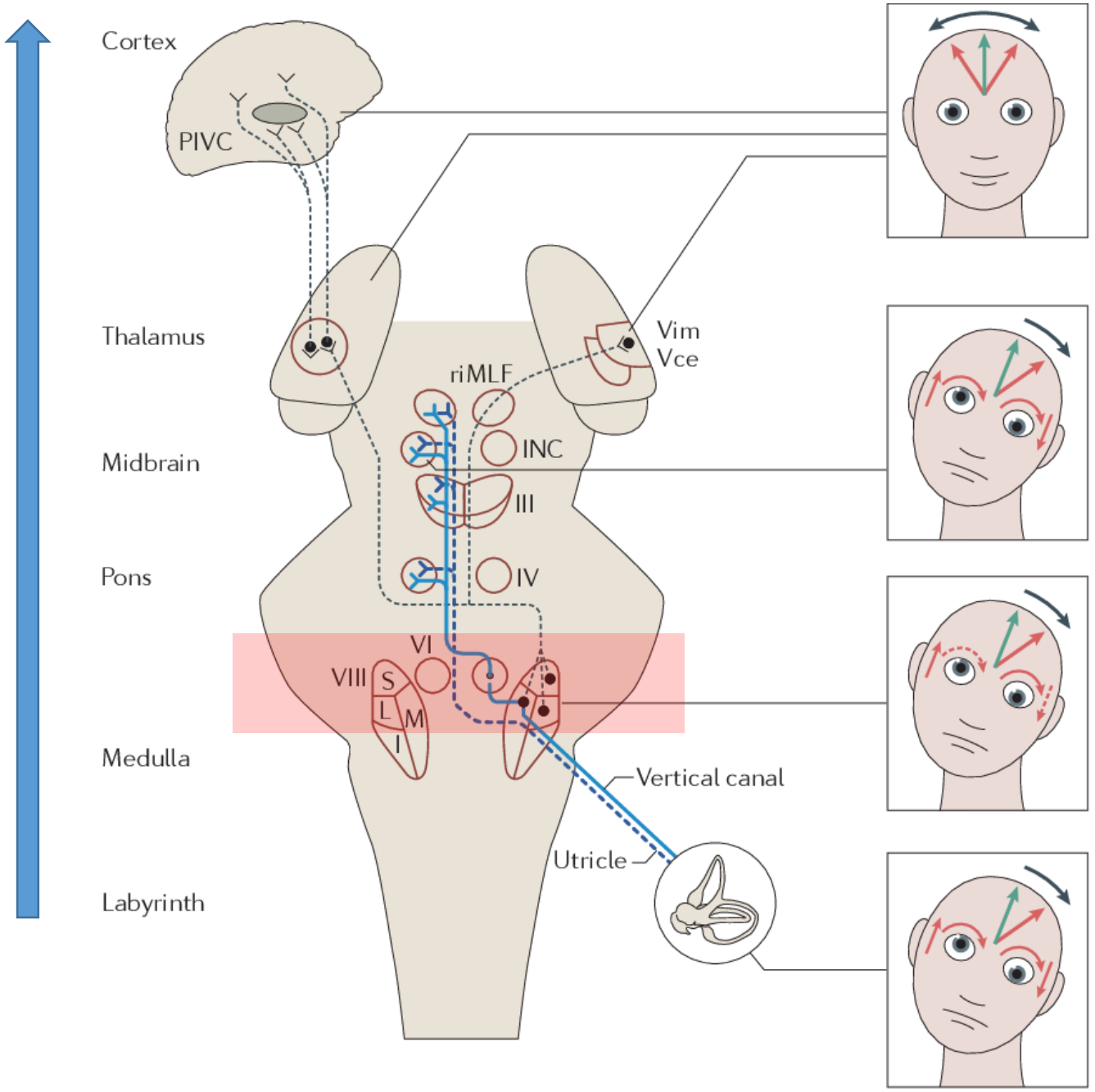
Brandt T. Vertigo: Its Multisensory Syndromes 1999



Thalamus, Cortex
Perception only
SVV +
Ocular torsion -
Skew deviation -
Head tilt -

Labyrinth, Medulla, Pons, Midbrain
Reflex plus Perception
SVV +
Ocular torsion +
Skew deviation +
Head tilt +

Brandt T, et al. Nature Reviews Neurology 2017



- **Decussation: mid- to-lower pons**

- Lesion **below** decussation: Tilt toward the lesion side (ipsiversive OTR)
- Lesion **above** decussation: Tilt away from the lesion side (contraversive OTR)
- Thalamus or cortex lesion: ipsi- or contra-versive SVV

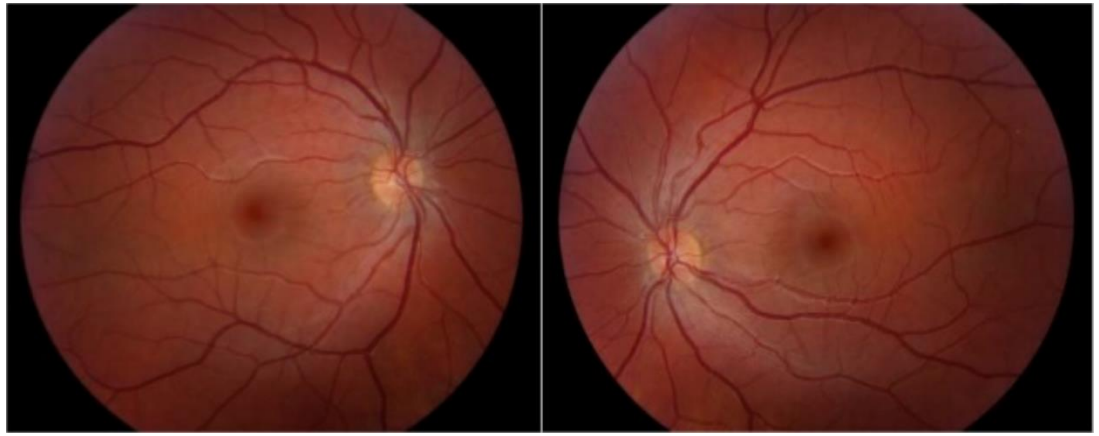
Brandt T, et al. Nature Reviews Neurology 2017

scanning laser ophthalmoscope (SLO)

- Scanning laser ophthalmoscope (SLO) for the quantification of eye torsion in the roll plane and to differentiate a monocular infranuclear lesion (e.g., third or fourth nerve) from a vestibular lesion. A torsion of both eyes (symmetric or asymmetric) indicates a vestibular imbalance.

scanning laser ophthalmoscope (SLO)

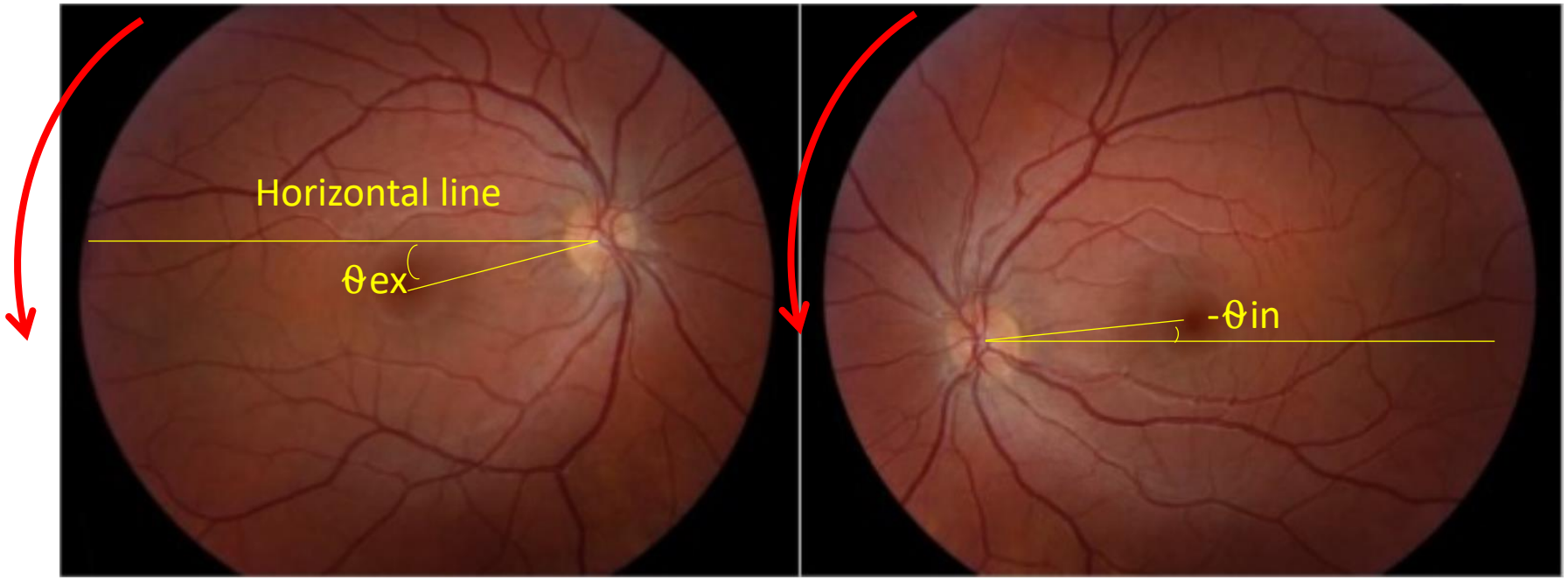
- a slightly excyclotropic position in the roll plane, i.e., counterclockwise rotation of the right eye and a clockwise rotation of the left eye. The normal range ($\pm$2 SDs) is from −1 to 11.5°.
- Pathological lesion shows an ipsiversive torsion of both eyes, i.e., excyclotropia of the ipsilateral eye and incyclotropia of the contralateral eye.



Absolute ocular torsion using fundus photography

Definition of Ocular torsion

- $\theta ex > 12.6^{o}$, or $\theta in < 0^{o}$, or $\theta ex - \theta in > 8.8^{o}$



Choi JW, et al. Eur Arch Otorhinolaryngol 2014

- Measurement of dynamic visual acuity (DVA), including the VOR reading test, i.e., determination of visual acuity under static conditions and during head turns. If there is a decrease of dynamic visual acuity of more than 0.2, this indicates a VOR deficit.

4.5 Posturography and Gait Analysis

- The parameters to be measured are body sway to the right or left, forward or backward, upward or downward with a subsequent analysis of the so-called sway path values (SP, “sway path”) and frequency.
- an automated analysis with a neuronal network allows differentiation between sensory (namely vestibular) deficits, functional dizziness, cerebellar ataxia, and orthostatic tremor.

Table 4.2 Disturbances of posture and gait control in peripheral vestibular disorders

Illness	Direction of deviation	Pathomechanism
Bilateral vestibulopathy	Different directions	Failure of vestibulospinal postural reflexes, exacerbated in the dark and on uneven ground
Acute unilateral vestibulopathy/ vestibular neuritis	Ipsiversive	Vestibular tone imbalance due to failure of the horizontal and anterior semicircular canal and utricle
Tumarkin's otolithic catastrophy	Lateral, ipsiversive, or contraversive (sudden falls)	Variations of endolymph pressure lead to an abnormal stimulation or inhibition of the otoliths and sudden vestibulospinal tone failure
Tullio phenomenon	Backward, contraversive, diagonal	Stimulation of the otoliths by sounds of certain frequencies, e.g., in cases of a syndrome of the third mobile windows
Vestibular paroxysmia	Contraversive or in different directions	Neurovascular compression of the vestibulocochlear nerve and excitation (rarely inhibition) of the vestibular nerve

Table 4.3 Disturbance of posture and gait control in central vestibular disorders

Illness	Direction of deviation	Pathomechanism
Downbeat nystagmus syndrome	Backward and forward	Vestibular tone imbalance in the pitch plane
Lateropulsion (Wallenberg's syndrome)	Ipsiversive, diagonal	Central vestibular tone imbalance (roll and yaw planes) with tilt of subjective vertical
Ocular tilt reaction (OTR)	Contraversive with mesencephalic lesions, ipsiversive with pontomedullary lesions, ipsi- or contraversive with unilateral cerebellar lesions (uvula or dentate nucleus)	Tone imbalance of the VOR in the roll plane with lesions of the vertical canals or otolith pathways
Paroxysmal ocular tilt reaction	Ipsiversive with mesencephalic excitation, contraversive with pontomedullary excitation or excitation of the vestibular nerve	Pathological excitation of the otolith or vertical canal pathways (VOR in the roll plane)
Thalamic astasia (often overlooked)	Contraversive or ipsiversive	Vestibular tone imbalance due to lesions of the posterolateral (rarely centromedian) thalamus
Vestibular epilepsy (rare)	Contraversive	Focal seizures due to epileptic discharges of the vestibular cortex

建議讀物

- Interacoustics playlist: https://www.youtube.com/@InteracousticsTV/playlists
- Ocular Tilt Reaction 張滋圃 https://youtu.be/n9_l8GH5F70?si=OL10W1RqV12LAVGk
- 臨床前庭醫學 主編 吳子明 劉博 韓軍良 人民衛生出版社
- 眩暈診治 by 田軍茹 人民衛生出版社
- 眩暈診治問與答 by 田軍茹 人民衛生出版社
- 電生理聽力學 華騰出版社
- Vertigo Its Multisensory syndromes by Thomas Brandt
- 大陸專家 陳鋼鋼 系列文章 https://nehshcedutw-my.sharepoint.com/:w:/g/personal/h311099_nehs_hc_edu_tw/EbVMWXvqVNhDtDb4qSpDyFYBrYwc-clvI1rWFbrf_o1Fdg?e=4QfC65
- 眼偏斜反應 https://nehshcedutw-my.sharepoint.com/:w:/g/personal/h311099_nehs_hc_edu_tw/EbVMWXvqVNhDtDb4qSpDyFYBrYwc-clvI1rWFbrf_o1Fdg?e=4QfC65
- http://BPPV.net (但時而連不上？) 大陸眩暈實驗室 系列文章: 3D內耳模型