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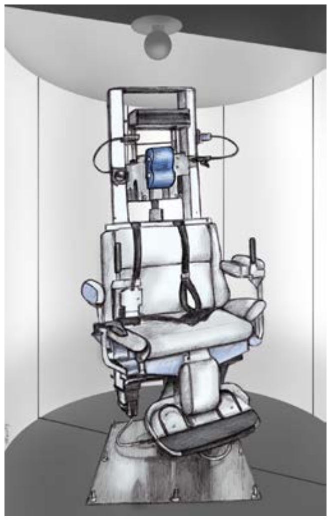


Fundamentals of Rotational Vestibular Assessment

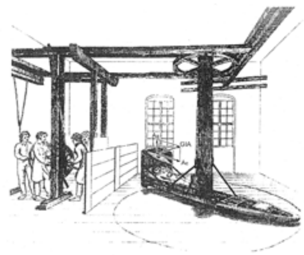
AudiologyOnline
Spring 2015

Chris Zalewski, Ph.D.

Learning Objectives

continued™

History of Rotational Testing



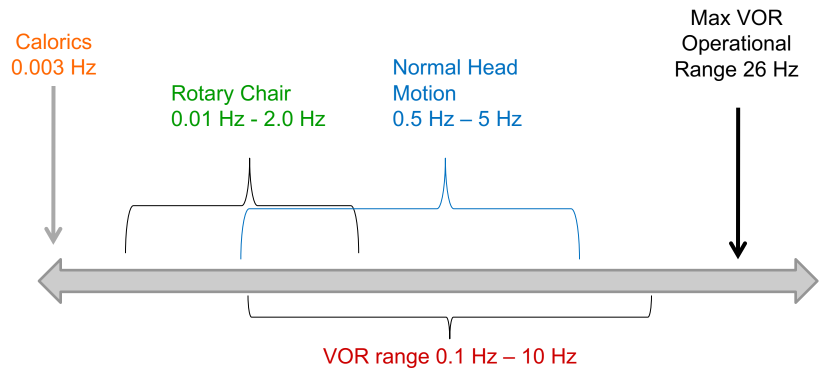
Modern Day Rotational Vestibular Testing

- Two primary stimuli employed during passive rotational testing:
  1. Sinusoidal Oscillation Testing
  2. Velocity Step Testing

- Other tests employed during passive rotational testing:
  1. VOR Suppression
  2. Oculomotor Assessment
  3. Unilateral Centrifugation
  4. Visual-Vestibular Enhancement
  5. OVAR
  6. Chair Head Impulse Test

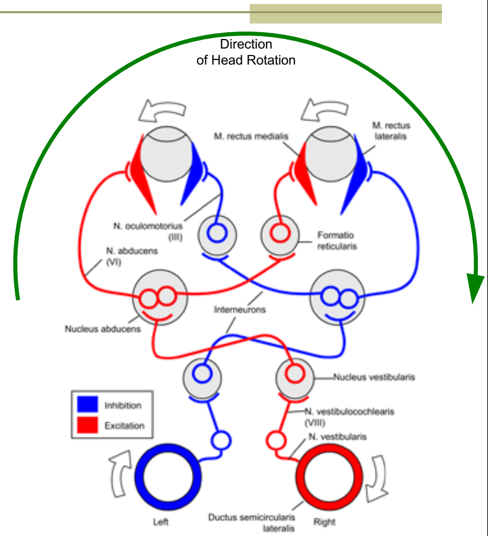
continued™

Operating Range of the Vestibular System



Rotational Vestibular Testing (RVT)
What it measures…

- Rotational vestibular tests primarily evaluate a specific component of vestibular function – *the horizontal canal-ocular reflex*
  - It is the same horizontal canal-ocular reflex (VOR) pathway that is evaluated during caloric irrigations
  - Physiologically however, the rotary chair test is that it stimulates both H-SCC and vestibular nerves simultaneously.
  - Rotation towards the right causes excitation of the right labyrinth AND inhibition of the left labyrinth
  - *Also assesses the central vestibular system including the vestibular nuclei and cerebellum (neural integrator) – although localizing power to these structures is less clear*

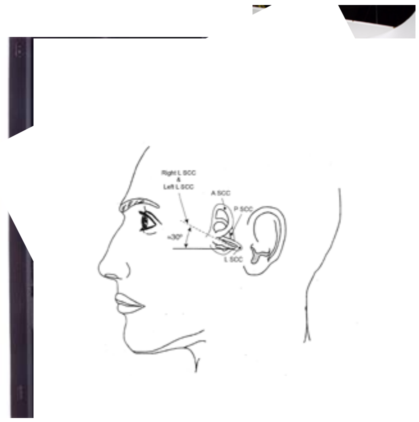


http://en.wikipedia.org/wiki/Vestibulo–ocular_reflex

Rotational Vestibular Testing

How it measures…

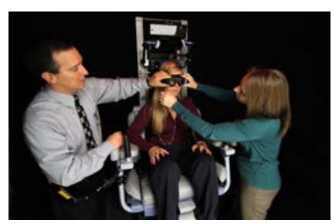
- Patient's head is tilted 30⁰ forward to place the H-SCC in the plane of rotation
- Chair is situated in a "lightproof" enclosure or may be "boothless" using vision-denied video goggles
- Standard electrode placement and / or video-oculography to measure the VOR
- Chair is turned by a torque motor for several cycles of sinusoidal rotation at octave frequencies (0.01, 0.02, 0.04, 0.08, 0.16, 0.32, & 0.64 Hz) and possibly higher. Step stimuli from 60⁰-300⁰/sec
- Patient is kept mentally alert (similar to the caloric & positional subtests of the VNG)
- Contraindicated medications should also be ceased 48 hours prior to the test

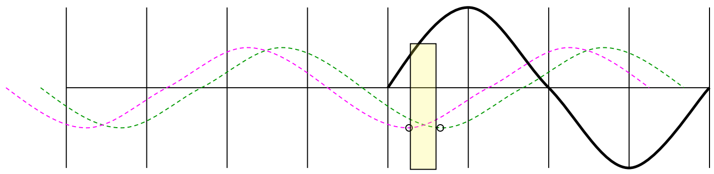


Rotational Vestibular Testing

The Fundamental Principle…

- Test Paradigm
  - Head rotation (sinusoidal acceleration) is firmly held in place and assumed to be equal to chair rotation
  - The patients horizontal eye position (VOR) is measured through video-oculography, and a nystagmus response is captured and recorded via software
  - The clinician can then examine the relationship between rotation (head movement) and eye movement





Sinusoidal Oscillation Testing

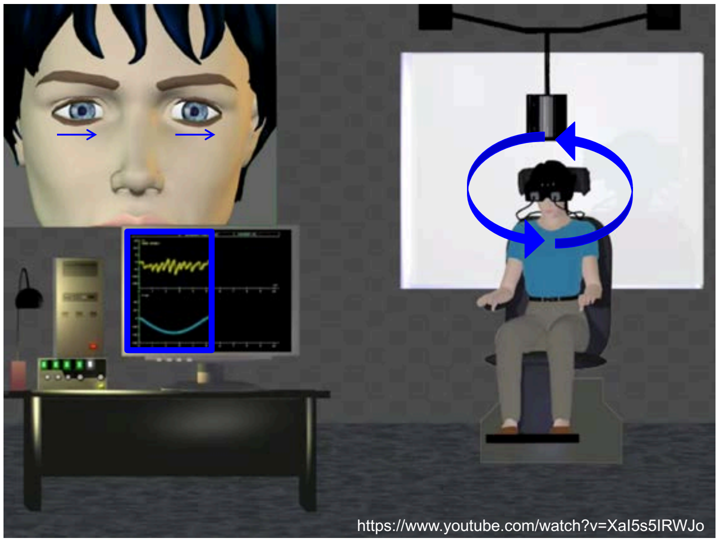
Rotational Vestibular Testing

Principal of rotational testing and the VOR response

continued™

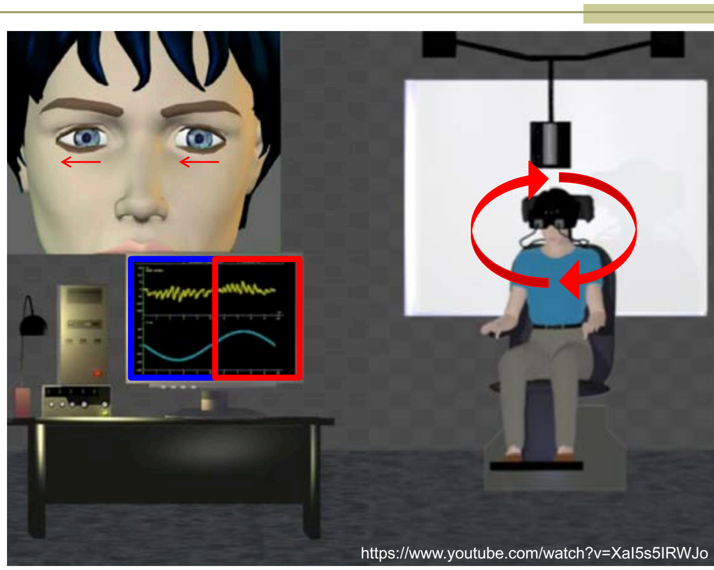
Rotational Vestibular Testing

Principal of rotational testing and the VOR response



Rotational Vestibular Testing

Principal of rotational testing and the VOR response



Sinusoidal Harmonic Acceleration

0.01 Hz

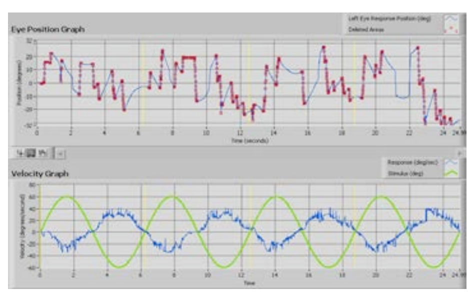
0.08 Hz

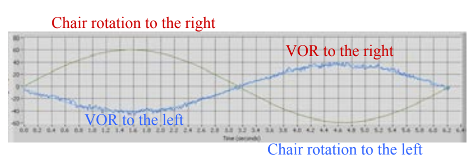
0.64 Hz

- The most widely used rotational test is the slow sinusoidal harmonic acceleration test
- Patient undergoes sinusoidal oscillations (back and forth rotations) at several different octave frequencies at a consistent 60^0 / sec head velocity
  - Octave frequencies of 0.01, 0.02, 0.04, 0.08, 0.16, 0.32 & 0.64 Hz (or higher)
  - Chair acceleration increases as the frequency of rotation increases
- Assesses the h-SCC, central systems and the vestibular nuclei

Sinusoidal Harmonic Acceleration

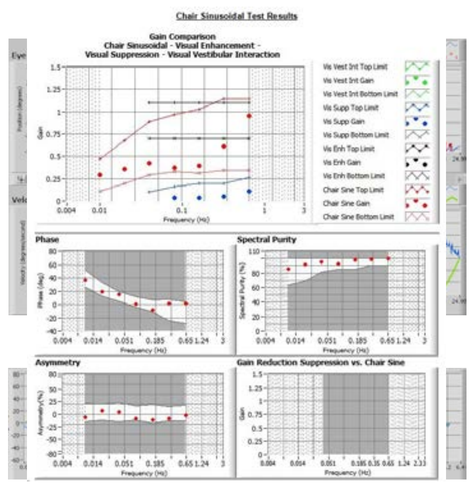
- As the chair and patient begin to rotate, a slow, compensatory eye movement is observed in the direction opposite the rotation – this is the VOR in action.
- The saccadic (fast) eye movement returns the eye to its primary central position and is noted to be in the same direction as the rotation
  - Right-Beating nystagmus during rightward rotation
  - Left-Beating nystagmus during leftward rotation
  - However, the slow phase is what is measured and analyzed as it is the *vestibular* response





Parameters of Sinusoidal Oscillation Testing

- The relationship between slow-phase eye velocity and head velocity is described by three parameters:
  - Gain: the ratio of peak eye velocity to head velocity
  - Phase Angle: The reaction time of opposing eye movement in response to head movement
  - Symmetry: The ratio of rightward and leftward maximum slow-phase eye velocities



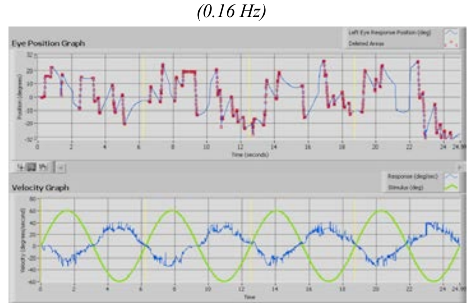
VOR Gain

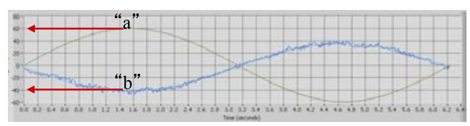
- Gain refers to the amplitude of the maximum slow-phase velocity of the nystagmus eye movement compared with the amplitude of the maximum velocity of the rotating chair (head)
- A gain of 1 indicates that the opposite slow-phase nystagmus velocity is equal to head movement velocity as chair (head) velocity decreases, the compensatory eye nystagmus gain also decreases).
- A gain of "0" is found when no eye movement occurs in response to chair (head) motion – i.e., no vestibular response
- Gain appears to be the most unstable parameter because it is closely related to the patient's state of mental alertness.
- Because *adequate gain is required for the analysis used to calculate the phase and symmetry,* every effort must be made to keep the patient mentally alert

Sinusoidal Oscillation Testing

- Again, if the VOR function is to produce equal and opposite eye movements to that of head movement than the SPEV plot in “b” would have been the exact mirror image of head velocity “a”
- However, it was not. The gain was only 66% [0.66 (0.4 / 0.6)]
- That is, the eyes did not move in the opposite direction but did not move at the same speed as the head (chair). In fact, the eyes only moved 66% the speed of the head (chair).

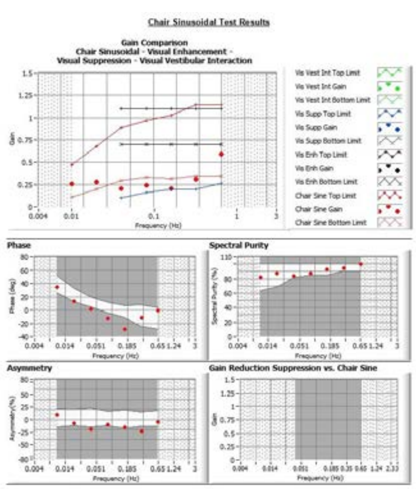
(0.16 Hz)



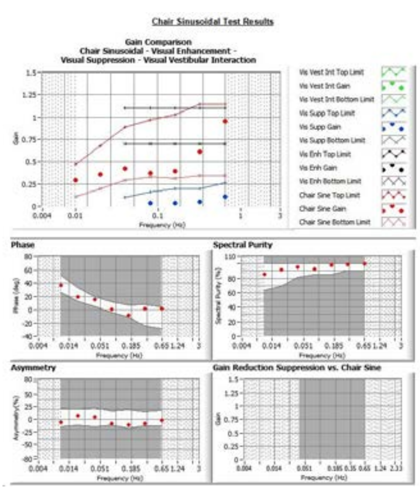


The Power of Tasking….

Insufficient Tasking



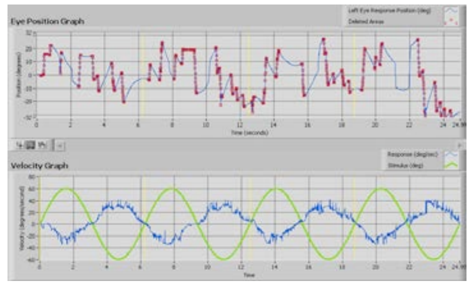
Sufficient Tasking

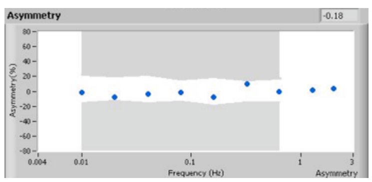


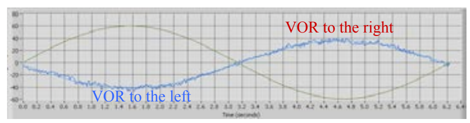
VOR Symmetry

(0.16 Hz)

- With rotation to the right, a leftward SPEV occurs. With rotation to the left, a rightward SPEV occurs.
- The symmetry parameter of the rotary chair reflects the ratio of the peak eye velocity between the right and left VOR



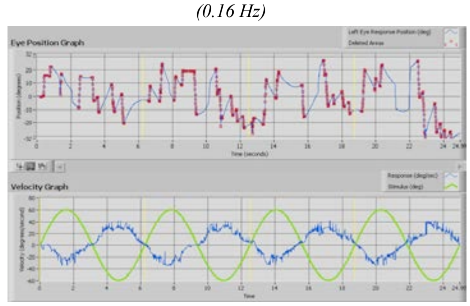


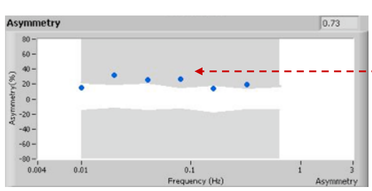


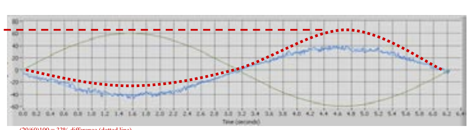
VOR Symmetry

(0.16 Hz)

- In acute unilateral peripheral lesions, a spontaneous nystagmus will often be present.
- This spontaneous nystagmus will produce an asymmetrical result by increasing (adding) the slow-phase velocity caused by the chair with the slow-phase velocity caused by SN







(20/60)100 = 33% difference (dotted line)

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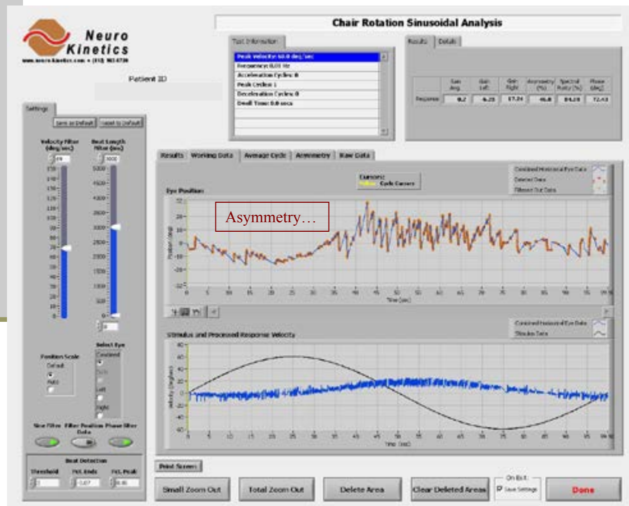
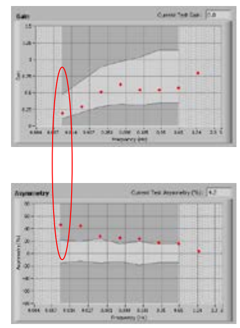
SHA Testing
0.01 Hz

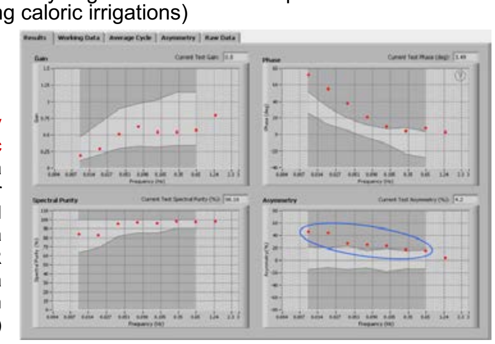




A note on asymmetries …

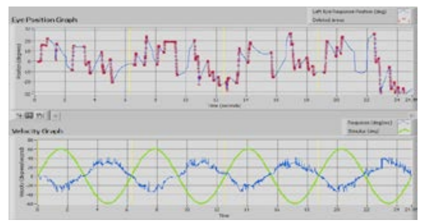
- It must be stressed that the symmetry measure is not a definite indication of laterality to the lesion, however, it is similar to directional preponderance on the caloric test
- In both cases, an asymmetry is most often the result of a spontaneous nystagmus with the asymmetry *usually* denoting the weaker ear (with the exception of irritative lesions – Meniere's, AN, PLF)
- A resolution of asymmetry is common over time and reflects central compensation (just as the resolution of spontaneous nystagmus and the consequential directional preponderance resolves during caloric irrigations)

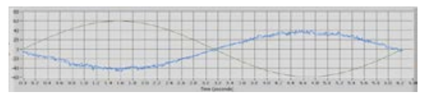
Abnormal chronic asymmetry implies a lack of physiologic compensation, suggesting a possible central vestibular system bias (directional preponderance) or a Result of persistent VOR asymmetry as a result of a central lesion (Leukoencephalopathy)



VOR Phase

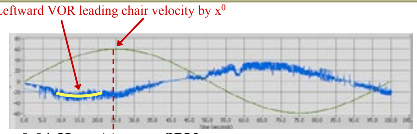
- The temporal (timing) relationship between the velocity of the head (chair) and that of the slow-phase component of the rotational-induced nystagmus.
- As the chair (head) begins to rotate, the nystagmus is observed to move in the *opposite* direction of the chair (head) rotation.
- The delay to which the eye moves in response to head movement is the phase
  - when perfect, the eyes move at exactly the same time and pace as the chair – only in the opposite direction.



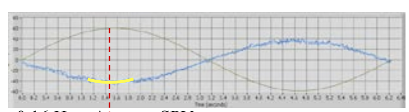


Phase Lead by Frequency - Normal

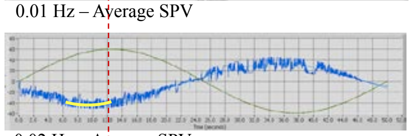
Leftward VOR leading chair velocity by x^0



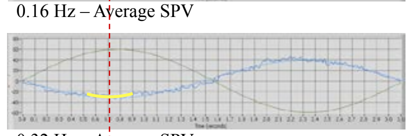
0.01 Hz – Average SPV



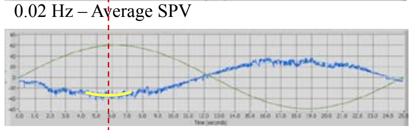
0.16 Hz – Average SPV



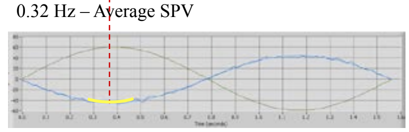
0.02 Hz – Average SPV



0.32 Hz – Average SPV



0.04 Hz – Average SPV



0.64 Hz – Average SPV

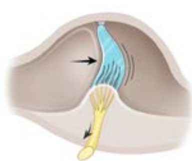
0.08 Hz – Average SPV

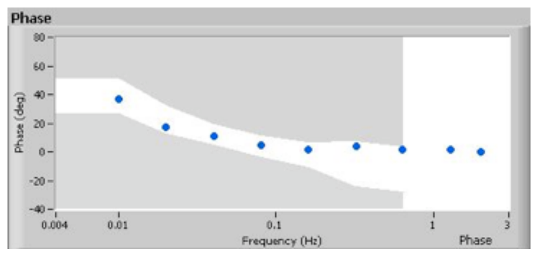
- The ability of the VOR to perform near equal and opposite progressively becomes poorer as stimulus Hz decreases
- At higher stimulus Hz's (>0.1 Hz), the eyes move nearly exact "opposite" of head velocity (180^0 in the other direction)

continued™

…and why for only low frequencies?

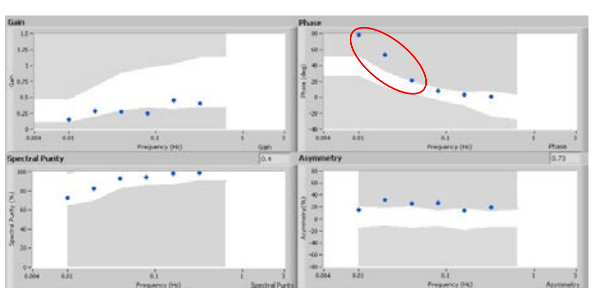
- The VOR performs poorly for lower frequency stimuli due to significantly reduced cupular mechanics. Because of this, the VOR must be assisted by other neural pathways.
- Velocity storage is primarily responsible for assisting the VOR for lower frequencies. This is clinically manifested by increasing the phase lead for the VOR for the lower frequencies (0.01-0.04 Hz).
- Therefore, velocity storage (the neural integrator) is *critical* for "helping out" the VOR performance for Hz's <0.1 Hz





Therefore, with peripheral vestibular lesions…

- "Knock-out" of the central vestibular velocity storage mechanism will often result in poor (reduced) integration of phase relationship between head movement and eye movement… resulting in even *earlier* phase lead times *– even with a previous vestibulopathy following central compensation*
- *Damaged central vestibular velocity storage seldom regains function even though the vestibular system centrally "rebalances" its tonic activity*
- The loss of velocity storage is so persistent that this abnormality on RVT persists for years following the vestibular lesion



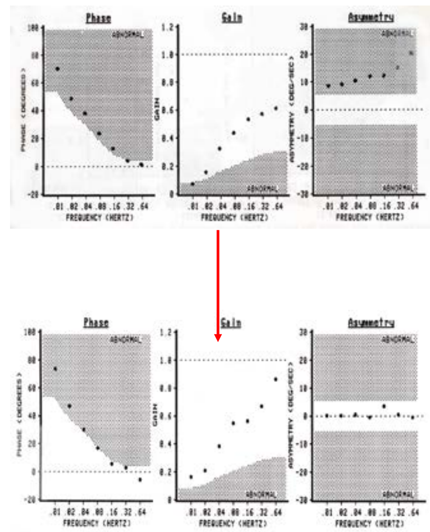
This response pattern of abnormal phase leads is by far the most common abnormality seen in the sinusoidal rotation test

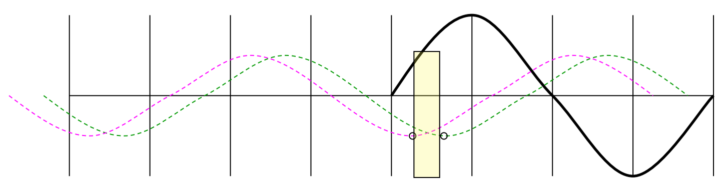
Evidence for Effective Compensation

- Following vestibular compensation and ablation of the rightward slow-phase spontaneous nystagmus, the pattern of RVT will change from “A” to “B”
- Most likely, after a few weeks
- Note the remaining abnormal phase lead secondary to persistent damage of velocity storage

A

B

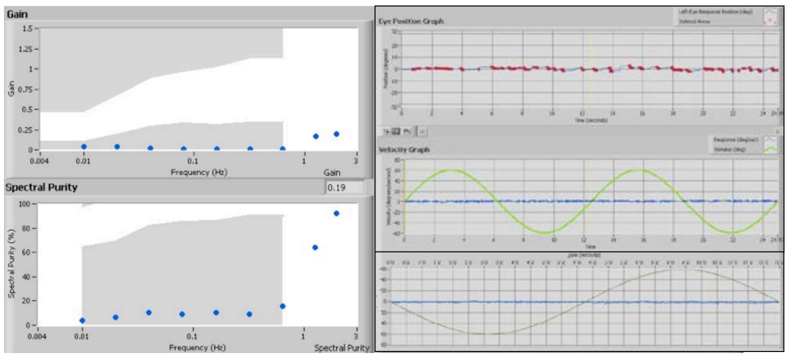




A few notes on SHA abnormalities…

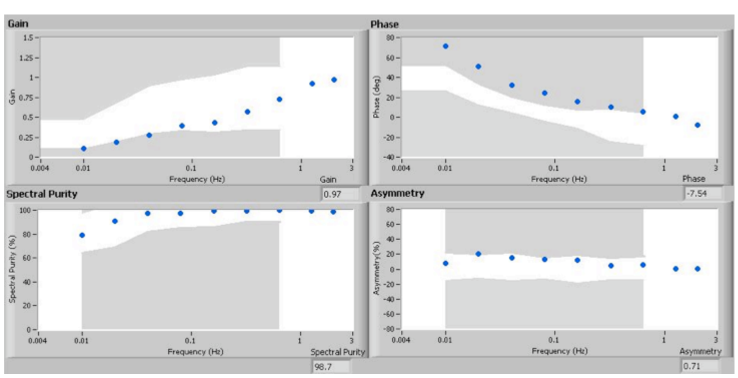
Other Types of Sinusoidal Oscillation Abnormalities

- This RVT pattern is consistent with a patient evidencing a bilateral loss of vestibular function
- This pattern, however, is actually not that common
- Most patient will show absent responses or reduced VOR gain at the lower oscillation Hz's, but will evidence normal or near normal gains as the highest Hz's – *even with absent ice-water caloric irrigations*



More Common of a Bilateral Finding…

- RVT results showing a low-frequency reduction in VOR gain with a significant low-frequency VOR phase lead.
- In the absence of a significant asymmetry, and a persistent reduction in VOR gain a bilateral peripheral vestibulopathy is suspected.



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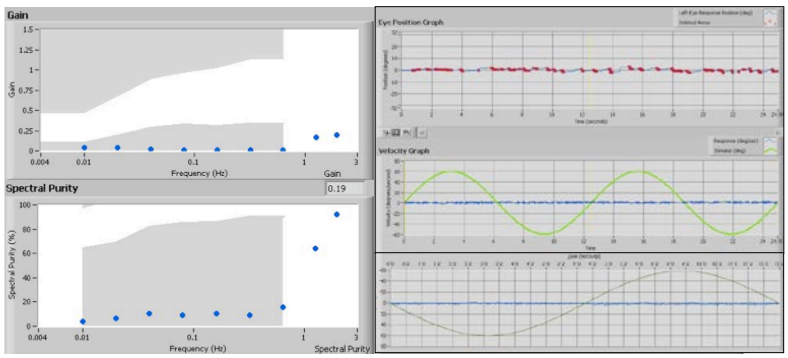
Be forewarned with decreased VOR gain responses …

- Because adequate gain is needed for the calculation of phase and symmetry, *if gain falls below normal levels, phase and symmetry should be interpreted with caution (if at all)…*



Sinusoidal Oscillation Abnormalities

Sinusoidal Harmonic Acceleration Testing			
Parameter	Abnormal Result	Possible Interpretation	Rule Out
GAIN	Low VOR gain for low Hz's (<0.04-0,08 Hz)	1. With concomitant abnl phase lead at low Hz's & asymmetry – uncompensated UVL on side of asymmetry 2. With no phase abnl's but abnl asymmetry, possible irritative or stable lesion (side uncertain) 3. No other abnl's & normal spectral purity, compensated UVL is likely	Insufficient alerting
	Low VOR gain for all Hz's	1. BVL given eyes open during test & asymmetry and phase uninterpretable 2. Vestibulotoxic medication, ageing, rare degenerative disorders of the brainstem and / or cerebellum (esp if calorics are normal)	Insufficient altering, restricted EOM, fixation
	High VOR gain for all or most	1. Cerebellar lesion (associated occulomotor abnormalities) 2. Has been observed in migraine and hydrops	Medications; stimulants
PHASE	↑ Low Hz Phase lead	1. Peripheral vestibular end-organ lesion / vestibular nuclei lesion 2. With concomitant asymmetry, uncompensated UVL (on side of asymmetry) 3. Acute vestibular end organ lesion; vestibular hydrops	Compare with Step Tests & calorics
	↑ High Hz Phase lead	1. CNS lesion; (associated occulomotor abnormalities)	Lateral Medullary Syndrome
	↓ Low / High Hz Phase lead	1. CNS lesion; (associated occulomotor abnormalities); consider lesions involving brainstem or posterior cerebellum; cerebellar nodulus	
SYMMETRY	Asymmetric SPV	1. Two or more consecutive abnormal Hz's; similar to DP on calorics (non-local) 2. With low Hz phase lead, uncompensated peripheral lesion on side of asymmetry	Unstable lesion with normal phase findings

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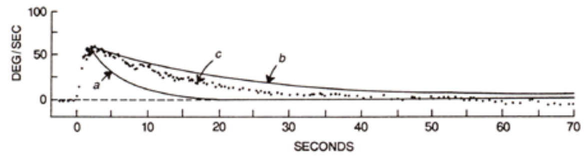


Velocity Step Testing, or Trapezoidal Step Testing

Velocity Step Testing

60^0 Velocity Step Test

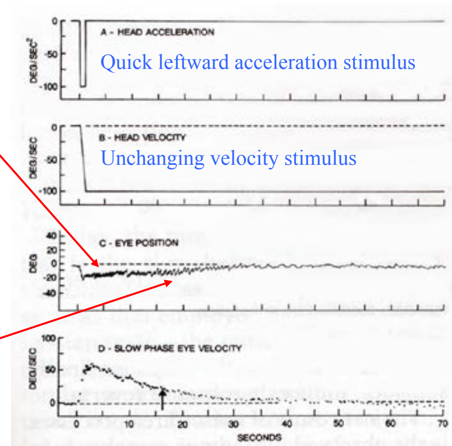
240^0 Velocity Step Test

- Low-Velocity Step Testing (commonly 60^0/sec velocity stimulus
- Used to test the velocity storage mechanism

- High-Velocity Step Testing (commonly 240^0/sec velocity stimulus (or greater)
- Used to test the symmetry of the vestibular system (think caloric irrigations)

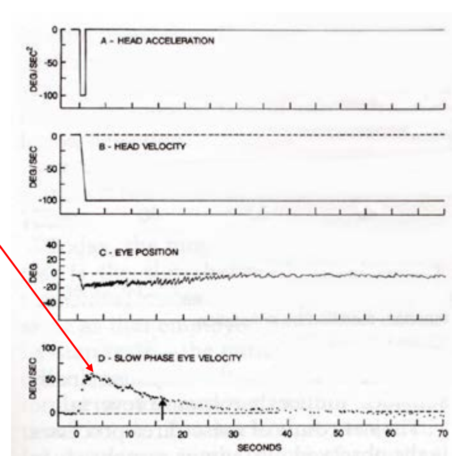
Velocity Step Testing

- In response to an abrupt leftward acceleration, a burst of (left-beating) horizontal nystagmus is observed
- Why left beating?
  - Excitation of the left h-SCC causes a rightward slow-phase with a leftward fast phase quick saccade to bring the eyes back to primary position
- The response gradually dissipates (without visual fixation)



Velocity Step Testing

- The velocity (intensity) plot of each slow-phase beat (the vestibular component of the nystagmus) shows the deteriorating *slow-phase* eye velocity
- The response is a rapid burst of SPEV with an exponential decline back to zero

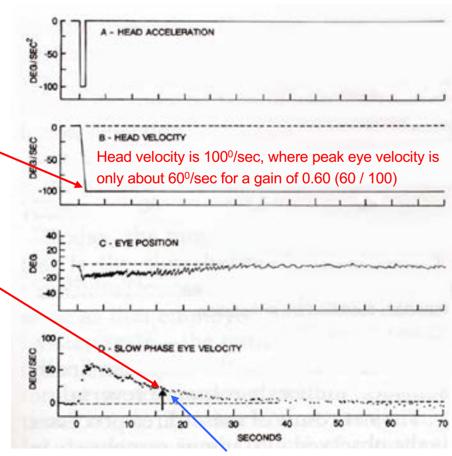


Two Principals of Step Measures…

- This response is measured by two parameters

    1. Gain – Ratio of *peak* eye velocity to head velocity

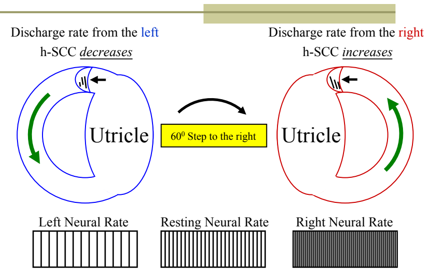
    2. Time Constant – The time, in seconds, for the response to decline to 37% of its peak value (or decline by 63% from its peak value)



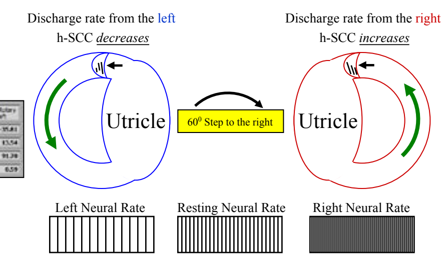
Time constant is approximately 16 seconds

Two Fundamental Step Paradigms

- 60^0 Step Test (low velocity step test)
    - Performed to measure the Time-Constant (TC) of the vestibular system
    - Indirect measure of velocity storage of the peripheral and central vestibular system
    - Is not intended to be a measure for lateralizing peripheral symmetry



Two Fundamental Step Paradigms

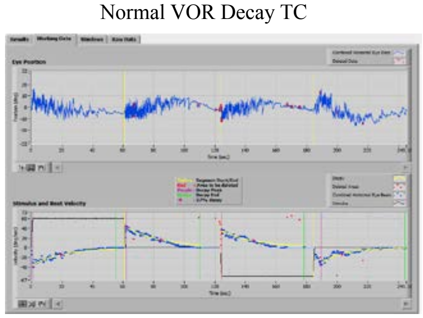


Chair acceleration burst to a 60^0/sec

Burst of right-beating nystagmus that declines over time

60^0 Velocity Step Test

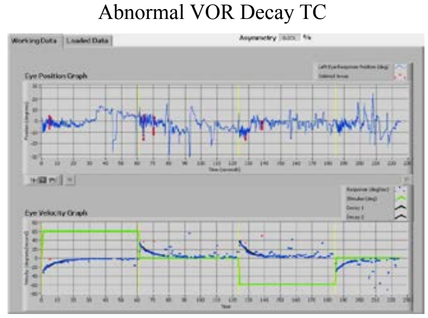
Normal VOR Decay TC



	Per-Rotary Right	Post-Rotary Right	Per-Rotary Left	Post-Rotary Left
Peak Vel. (deg/sec)	-40.14	43.58	36.67	-35.81
Decay Time(sec)	18.47	22.38	20.82	13.54
Validity	94.81	89.64	69.95	91.70
Gain	0.67	0.72	0.61	0.59

Asymmetry -2.75 %

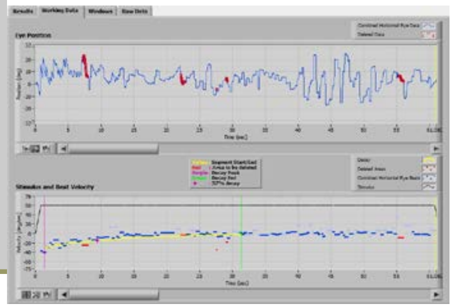
Abnormal VOR Decay TC

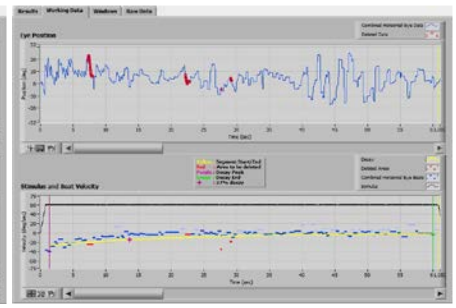


Peak Vel. (deg/sec)	-28.225	30.174	36.447	-28.058
Decay Time(sec)	8.522	8.239	6.944	6.973
Validity	75.592	73.626	75.534	79.704
Gain	0.471	0.505	0.603	0.471

A Common Error in 60^0 Velocity Step Test Analysis

Which is the correct interpretation?





	Per-Rotary Right	Post-Rotary Right	Per-Rotary Left	Post-Rotary Left
Peak Vel. (deg/sec)	-39.48	34.80	29.93	-29.75
Decay Time(sec)	8.09	8.62	6.88	10.72
Validity	77.86	66.63	85.01	78.47
Gain	0.66	0.58	0.50	0.49

	Per-Rotary Right	Post-Rotary Right	Per-Rotary Left	Post-Rotary Left
Peak Vel. (deg/sec)	-39.48	34.80	29.93	-29.75
Decay Time(sec)	12.27	8.62	6.88	10.72
Validity	70.38	66.63	85.01	78.47
Gain	0.66	0.58	0.50	0.50

Two Fundamental Step Paradigms

- 60^0 Step Test (low velocity step test)
  - Performed to measure the Time-Constant (TC) of the vestibular system
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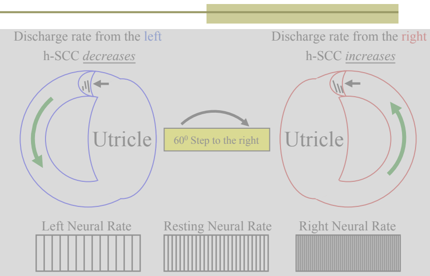
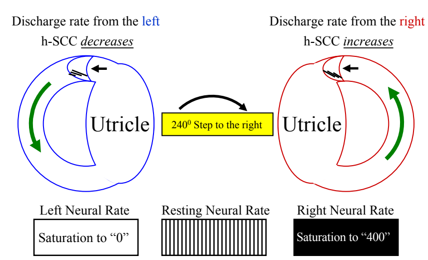
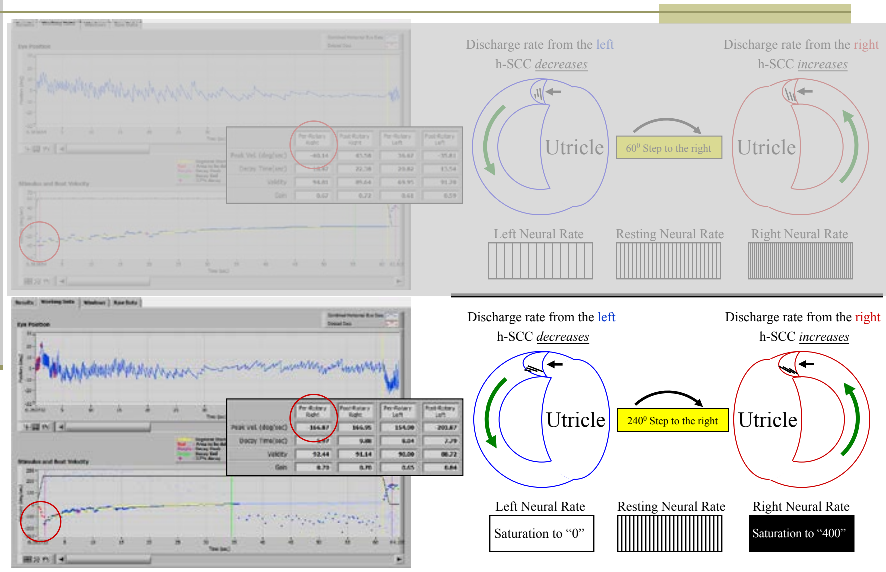


- 240^0 Step Test (high velocity step test)
  - Measures the peak eye velocity of the vestibular periphery to a high



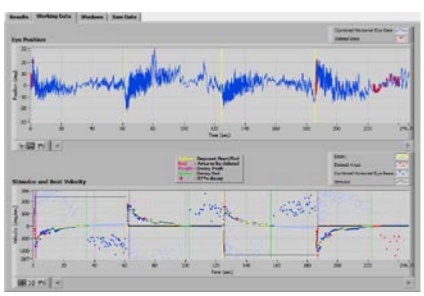
continued

Two Fundamental Step Paradigms



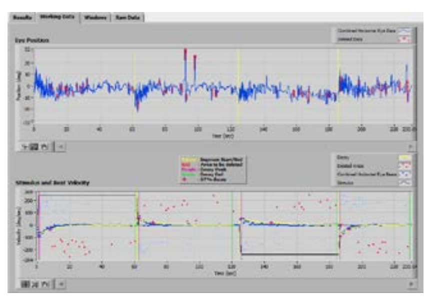
240^0 Velocity Step Test

Symmetrical (Normal) VOR PEV's



	Per-Rotary Right	Post-Rotary Right	Per-Rotary Left	Post-Rotary Left
Peak Vel. (deg/sec)	-166.87	166.95	154.90	-201.87
Decay Time(sec)	5.97	9.88	8.04	7.79
Validity	92.44	91.14	90.00	88.72
Gain	0.70	0.70	0.65	0.84
Asymmetry	6.79 %			

Asymmetrical (Abnormal) VOR PEV's



	Per-Rotary Right	Post-Rotary Right	Per-Rotary Left	Post-Rotary Left
Peak Vel. (deg/sec)	-94.04	52.55	51.71	-89.44
Decay Time(sec)	6.97	8.95	18.25	3.35
Validity	90.07	93.54	90.36	77.37
Gain	0.39	0.22	0.22	0.37
Asymmetry	27.53 %			

$94.04 + 89.44 = 183.48$

$52.55 + 51.71 = 104.26$

Δ 27.53%

Another Common Error in Velocity Step Test Analysis

	Per-Rotary Right	Post-Rotary Right	Per-Rotary Left	Post-Rotary Left
Peak Vel. (deg/sec)	-37.93	37.88	34.40	-31.74
Decay Time(sec)	12.37	13.81	13.29	14.82
Validity	88.38	79.14	83.77	87.90
Gain	0.63	0.63	0.57	0.53
Asymmetry	-1.84 %			

Comparison to the laterality predictability from calorics ?

- Baloh et al (1979) subjected 48 patients with unilateral peripheral vestibular lesions (patients with significantly reduced unilateral caloric responses) to a series of rightward and leftward velocity steps

- *They found that asymmetries were detected most consistently:*
  - In patients with severe lesions, and
  - Using the largest velocity step stimuli (up to 256^0/sec)
  - 87% sensitive with unilateral caloric *absence*
  - 40% sensitive with unilateral caloric *paresis*

- *Conclusions: caloric test is more sensitive than the velocity step test in detecting unilateral peripheral vestibular lesions*

- *However, the power of low velocity step testing does indicate functional status of the central vestibular velocity storage system – something currently lacking in caloric irrigations*

Reliability and Repeatability of Rotational Testing

Interlaboratory variability of rotational chair test results

JOEL A. GOEBEL, MD, FACS, JASON M. HANSON, MD, DOUGLAS G. FISHEL, BS, and THE INTERLABORATORY ROTATIONAL CHAIR STUDY GROUP,* St. Louis, Missouri

Interlaboratory variability of rotational chair test results II: Analysis of simulated data

JOSEPH M. FURMAN, MD, PhD, JOEL A. GOEBEL, MD, JASON HANSON, MD, TIMOTHY SCHUMANN, BS, and the INTERLABORATORY ROTATIONAL CHAIR STUDY GROUP,* Pittsburgh, Pennsylvania, and St Louis, Missouri

Velocity Step Testing Abnormalities

Velocity Step Testing			
	Abnormality	Possible Interpretation	Rule Out
60^0 / sec	Shortened time constant (<10 sec)	1. Peripheral UVL if oculomotor testing is normal, likely labyrinth or VIII Nerve 2. At 60^0 or 100^0 / sec, information is from both labyrinths 3. Non-localizing cupular time constants plus velocity storage – gains should be >0.3; if not, consider migraine	Inattention; too much blinking; bilat loss; fixation
	Prolonged time constant (>33 sec)	1. Very Rare. 2. Usually consistent with a central lesion impacting the midline cerebellum (nodulus region) 3. Confirm with decreased phase leads	Drug Interaction
	If 3 of 4 time constants are abnormal	1. Abnormal study; non-localizing	Inattention; too much blinking
240^0 / sec	Consider peak slow phase velocity; >30% difference between CW & CCW directions?	1. Significant asymmetric results in peak SPV indicate peripheral UVL and side of loss	Eye closure (eyes must be open when chair starts & stops)

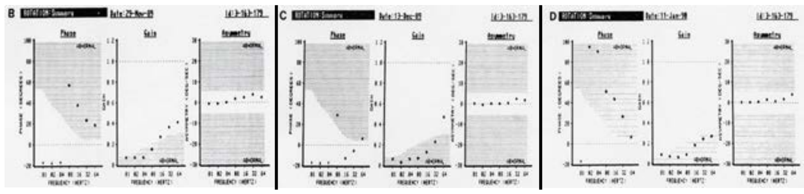
Clinical Application

So what is the clinical application?

- The caloric response is restricted to such a long Hz stimulus (0.003 Hz) that rotational testing offers a more functional level of stimulus from which to assess vestibular function.
  - Given that the results of a bilateral caloric weakness reflects such as low-Hz stimulus, the absence of a caloric response does NOT indicate an absence of vestibular function. In fact, a patient may have absent caloric responses, but elicit normal rotational responses at higher Hz's of rotation. *This is often an early indicator of vestulo-toxcicity*
- Overall, results of rotational testing should be interpreted with some degree of caution since only a fraction of the VOR is being evaluated. We must take into account other factors that may affect vestibular function such as the otolithic organs, the remaining semicircular canals, the brainstem, and possible cognitive processes (such as prediction)
- Finally, knowing the degree of vestibular loss may also be useful in determining whether a patients balance rehabilitation should enhance residual vestibular function or retrain the individual to rely more on somatosensory and visual cues

So what is the clinical application?

- An additional strength of rotational testing appears to be its sensitivity to monitor changes within the vestibular system, particularly in the early detection of bilateral, peripheral vestibular disease (such as with vestibulo-ototoxicity).



- Rotational testing is most useful in determining the presence of bilateral peripheral vestibular loss
- Another effective application of rotational testing is its use with special populations, especially infants and young children in whom caloric irrigations are contraindicated.

Special Populations - Children

- The majority of children demonstrate vestibular responses to caloric and rotational stimuli by 2 months of age
- By 10 months of age, the absence of VOR responses can be considered abnormal
- Ice water and rotational vestibular responses can sometimes be elicited in neonates, but lack of a response in a child less than 6 months of age is not necessarily abnormal
- Children are more likely to fear vestibular testing than adults
- Inattentiveness and lack of experience can often be insurmountable obstacles

Rotational Vestibular Testing

- Advantages :
  - The rotational stimulus is less bothersome to the patient because it does not create the vertigo and vagal symptoms associated with the caloric test
  - The mechanical artifacts associated with delivering other stimuli (caloric stimulus) to the inner ear are not present in rotational testing (i.e., a more accurate stimulus/response is possible)
  - The rotational stimulus is more natural because it attempts to stimulate natural environment motion (0.01-0.64 Hz), and subsequently a wider portion of the vestibular system's operating range.
  - Multiple gradations of the stimulus can be presented in a short time
  - Small changes within the vestibular-ocular reflex can be monitored more effectively secondary to the more accurate stimulus delivery

Rotational Vestibular Testing

- Disadvantages:
  - Not widely available (cost)
  - Main limitation is its lack of sensitivity in detecting chronic unilateral vestibular hypo-function
  - Rotational testing stimulates both H-SCC and superior vestibular nerves simultaneously. Because of the bilateral response, it is difficult to interpret laterality from the results.
  - Fails to evaluate anything greater than the horizontal vestibulo-ocular reflex
  - Mental alertness has been shown to have a significant effect on the purity of the nystagmus response. This may prove to be troublesome in light of your physical separation from you patient – many of whom may have a (significant) hearing loss.
  - Excessive random eye movements produced a significant decrease in the purity of the measured nystagmus because they introduce energy at Hz's other than that of the intended rotation frequency. Thus, even if gain is normal, phase and symmetry may be adversely affected.

Thank you

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czalewski1@verizon.net