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Effect of high-performance jet fighter flight on the vestibular system

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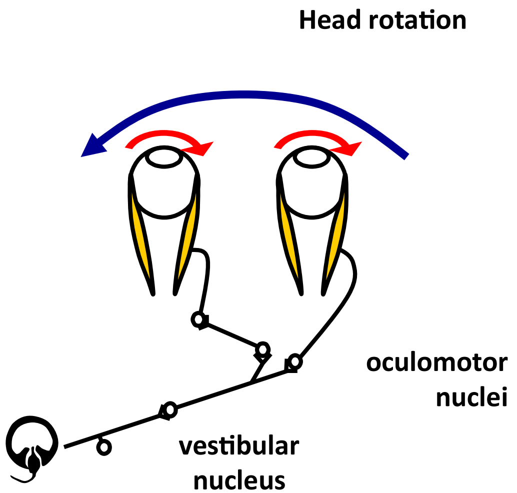
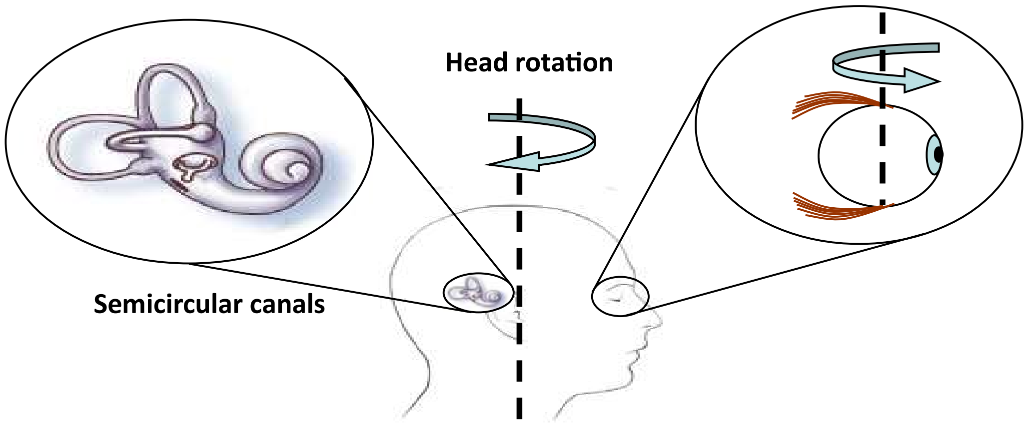
Vestibulo-ocular reflex

The rotational vestibulo-ocular reflex (rVOR) stabilizes vision during head rotations





Key features of rVOR

- Eyes rotates at the same velocity of the head
- Very fast (10 ms latency)
- It stabilizes the entire retina (ideally gain=1)
- Not ideal for stabilizing vision during slow movements
- Works around 3 rotation axis – 6 "gyroscopes" (the semicircular canals)
- Integrated with vision and proprioception (Cerebellar control)

Vestibulo-ocular reflex in flight

Two types of head rotation

1. Head on body (active natural head movements)
2. Passive, whole body (aircraft rotations)

rVOR is correct:

- For stabilization of external target (both types)
- For stabilization of cockpit targets (only type 1)

In addition, GIA tilts, high-g and complex combination of head rotation stimuli (e.g. cross-coupling) may influences rVOR function

Research question

- Vestibulo-ocular reflex (VOR) is not functional when looking at cockpit targets (e.g. instruments)
- Head movements during passive aircraft motion induces conflicts with perceived vertical (g-direction)

- Tactical, High-performance aircrafts have
  - high rate of turns → Strong inappropriate VOR
  - high g-load → high vestibular-otolith conflicts

- **Does the vestibulo-ocular reflex changes with prolonged exposure?**

Conflicting reports (1/2)

Higher Gain in pilots than non pilot controls

- Schwarz U, Henn V.; Vestibular habituation in student pilots. *Aviat Space Environ Med* (1989)
- Lee MY, Kim MS, Park BR; Adaptation of the Horizontal Vestibuloocular Reflex in Pilots. *Laryngoscope* (2004)

The Laryngoscope
Lippincott Williams & Wilkins, Inc.
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Adaptation of the Horizontal Vestibuloocular Reflex in Pilots

Moon Young Lee; Min Sun Kim; Byung Rim Park

No difference between pilots than non pilot controls

- Ahn SC. Short-term vestibular responses to repeated rotations in pilots. *Aviat Space Environ Med* (2003)
- Kuldavletova O, Tanguy S, Denise P, Quarck G.; Vestibulo-Ocular Responses, Visual Field Dependence, and Motion Sickness in Aerobatic Pilots. *Aerosp Med Hum Perform* (2020)

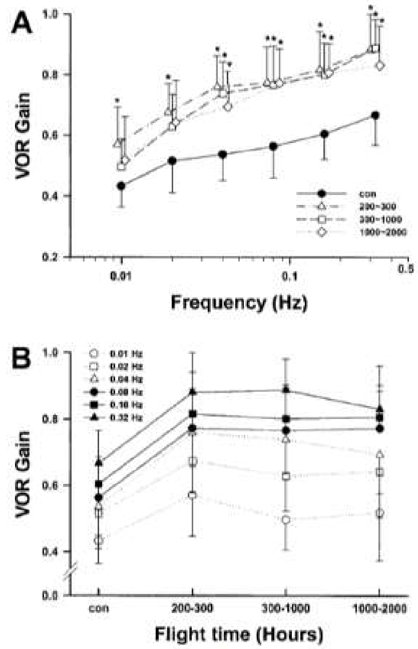

Fig. 1. Vestibuloocular reflex (VOR) gain changes as a function of flight time at each frequency (A) and frequency-dependent gain changes according to flight time (B).

Conflicting reports (2/2)

These studies used rotating chairs and focused on «low frequency» responses (0.01-0.32 Hz).

Functional gaze stabilization through VOR works higher frequencies (0.5 – 5 Hz)

- Clinically, the VOR is tested with « head impulses»

Only **one study** used the Head Impulse Test

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ORIGINAL ARTICLE

Assessment of the vestibuloocular reflex in fighter pilots with the video head impulse test

FRANCISCO CARLOS ZUMA E MAIA[1,2], PEDRO LUIZ MANGABEIRA ALBERNAZ[3,4], RENATO CAL[5,6], THAÍSA RODRIGUES BRUSCO[7] & SADY SELEIMAN DA COSTA[8]

Table I. VOR gain reflex for the six semicircular canals (Control Group × Groups 2 and 3).

Canals	Control Group (n = 14)		Groups 2 + 3 (n = 20)		p-values*
	Mean	SD	Mean	SD	
GLL	0.94	0.05	0.93	0.06	0.890
GRL	0.99	0.06	1.02	0.08	0.215
GLA	0.91	0.06	0.91	0.10	0.979
GLP	0.98	0.08	0.91	0.06	0.013*
GRA	0.95	0.09	0.93	0.08	0.543
GRP	0.96	0.09	0.93	0.10	0.821

*Statistically significant by Student t-test ($p < 0.05$).
GLL, gain of the left lateral canal; GRL, gain of the right lateral canal; GLA, gain of the left anterior canal; GLP, gain of the left posterior canal; GRA, gain of the right anterior canal; GRP, gain of the right posterior canal.

Finding: Gain reduction in a single vertical canal
Limitations: Small number of subjects, mixed flight exposures and experience

Experimental question

Evaluate VOR changes using Video Head impulse Test in pilot as function of

- Overall exposure to flight (overall flight hours)
- Exposure to different flight conditions (Jet vs non-supersonic)

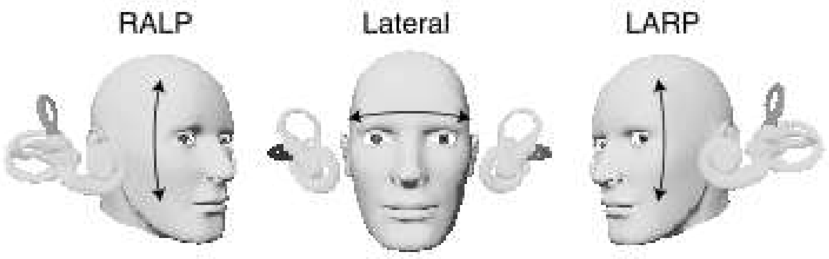
Two studies

1. Large cohort (90 pilots), cross-sectional study with 3 groups
   - TRAINEE : 69 Pilots - < 300 h - non-high-performance/non aerobatic
   - HIGH-PERFOMANCE: 15 Pilots - > 3000 h - high-performance aircraft (F/A 18)
   - NON-HIGH-PERFORMANCE: 7 Pilots - > 3000 h - non-high-performance aircraft (PC/7)
2. Small cohort (4 pilots) observational, follow-up study
   - Three time points:
     1. <300 h; no aerobatic; no F/A 18
     2. >300 & <2000 h; aerobatic; no F/A 18
     3. >2000 h; aerobatic; F/A 18

Conflicting reports (2/2)

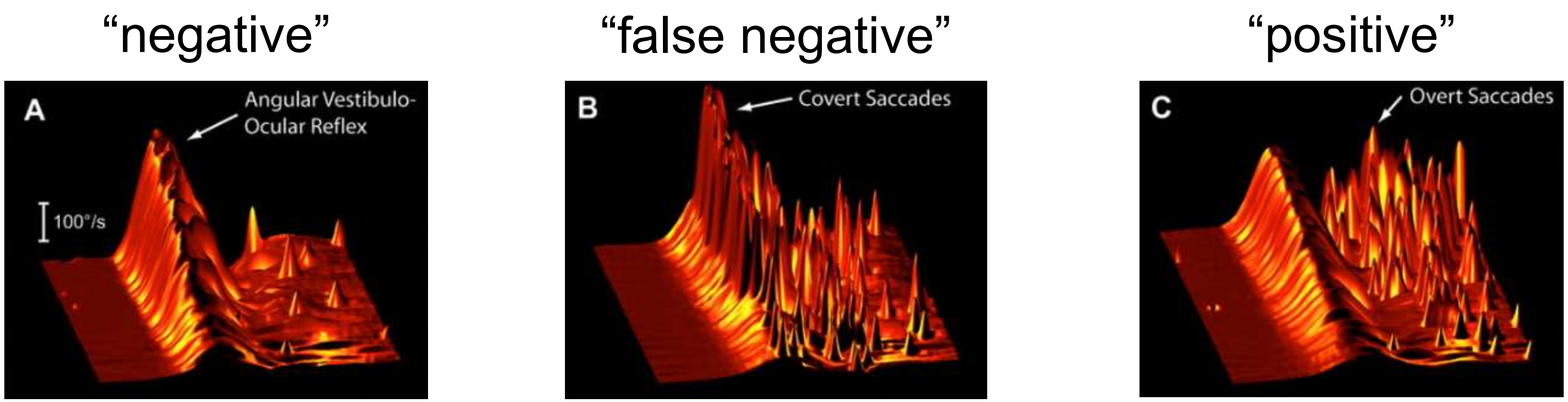
Clinical video Head Impulse Test (vHIT)

- Rapid head rotation in the plane of a canal
- Tracking of compensatory eye movement with video-oculography
- measures canal-specific gains of the vestibulo-ocular reflex (VOR)
- detects covert catch-up saccades



250 Hz or more

eye: video
head: accelerometer



MacDougall, Weber et al. 2008-2013

Results Study 1 (1/2)

Lower rVOR gains in High-performance Group compared to Trainee and Non-high performance for <u>at least 3 vertical canals</u>

	Group 1 (Trainee Group) n=68	Group 2 (High-performance Group) n= 15	Group 3 (Non-High-performance Group) n= 8
Horizontal Left Lateral	0.901 ± 0.057*	0.846 ± 0.040*	0.87 ± 0.041
Horizontal Right Lateral	0.954 ± 0.057	0.962 ± 0.043	0.98 ± 0.059
Vertical Left Anterior	0.931 ± 0.232*	0.735 ± 0.106*§	1.15 ± 0.119*§
Vertical Right posterior	0.957 ± 0.288*	0.736 ± 0.064*§	1.15 ± 0.160§
Vertical Left Anterior	1.014 ± 0.183*	0.846 ± 0.061*§	1.08 ± 0.054§
Vertical Right Anterior	1.072 ± 0.163*	0.876 ± 0.267*§	1.07 ± 0.165

* $p < 0.05$ compared with Group 1; § $p < 0.01$ compared with Group 2.

Results Study 1 (2/2)

Statistically higher incidence of pathological results of the video Head impulse Test in for the vertical canals in High-performance Group

	Group 1 (Trainee Group) n=68	Group 2 (High-performance Group) n= 15	Group 3 (Non-High-performance Group) n= 7
Pathological in at least 1 *Vertical* SCC	12/68 (18%)*	8/15 (53%)*	0/7 (0%)*

Results Study 2 (1/3)

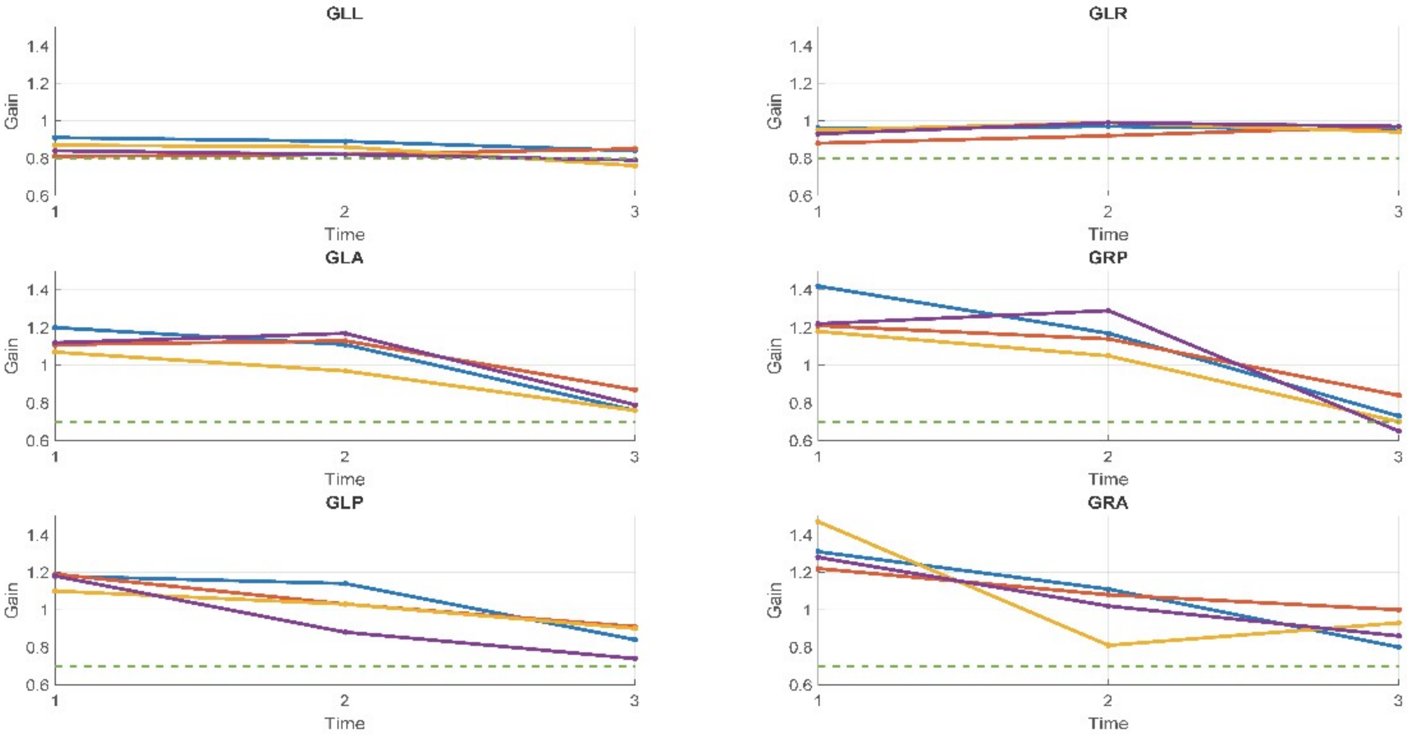
A significant reduction was observed only for the vertical canals.

	Time 1	Time 2	Time 3	p-value (for the effect of time points)
Flight experience	<300 h; no aerobatic; no F/A 18	>300 & <2000 h; aerobatic; no F/A 18	>2000 h; aerobatic; F/A 18	
Horizontal Left Lateral	0.855 (0.825; 0.89)	0.84 (0.82; 0.875)	0.815 (0.775; 0.845)	0.105
Horizontal Right Lateral	0.94 (0.905; 0.955)	0.98 (0.945; 0.99)	0.96 (0.945; 0.97)	0.257
Vertical Left Anterior	1.115 (1.09; 1.16)	1.12 (1.04; 1.15)	0.775 (0.76; 0.83)	0.038*
Vertical Right posterior	1.215 (1.195; 1.32)	1.155 (1.095; 1.23)	0.715 (0.675; 0.785)	0.038*
Vertical Left Anterior	1.18 (1.14; 1.185)	1.03 (0.955; 1.085)	0.87 (0.79; 0.905)	0.013*
Vertical Right Anterior	1.295 (1.25; 1.39)	1.05 (0.915; 1.095)	0.895 (0.83; 0.965)	0.038*

Results Study 2 (2/3)

A consistent significant reduction was observed only for the third time point.

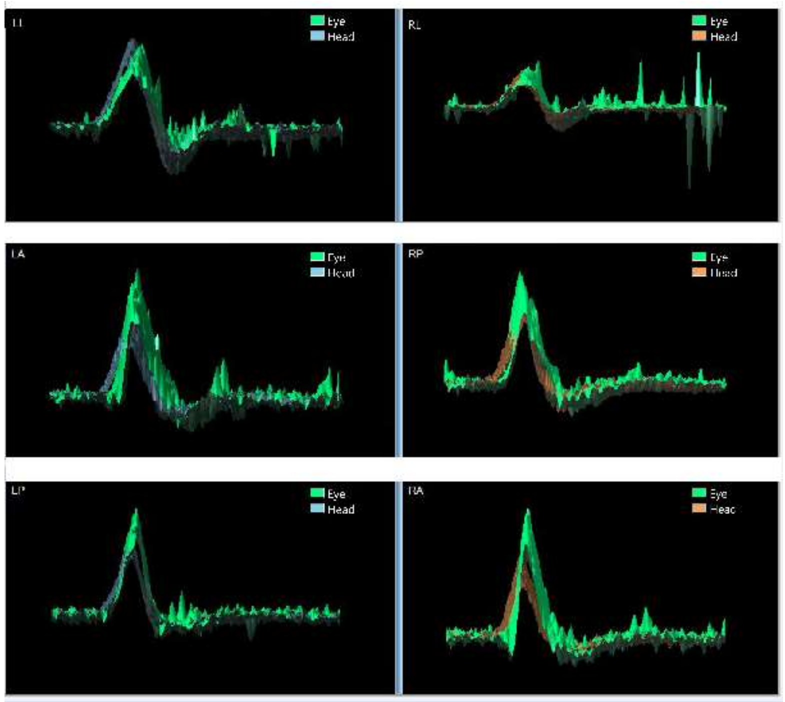
Two pilots had results below the threshold (green dotted line) at time point 3.



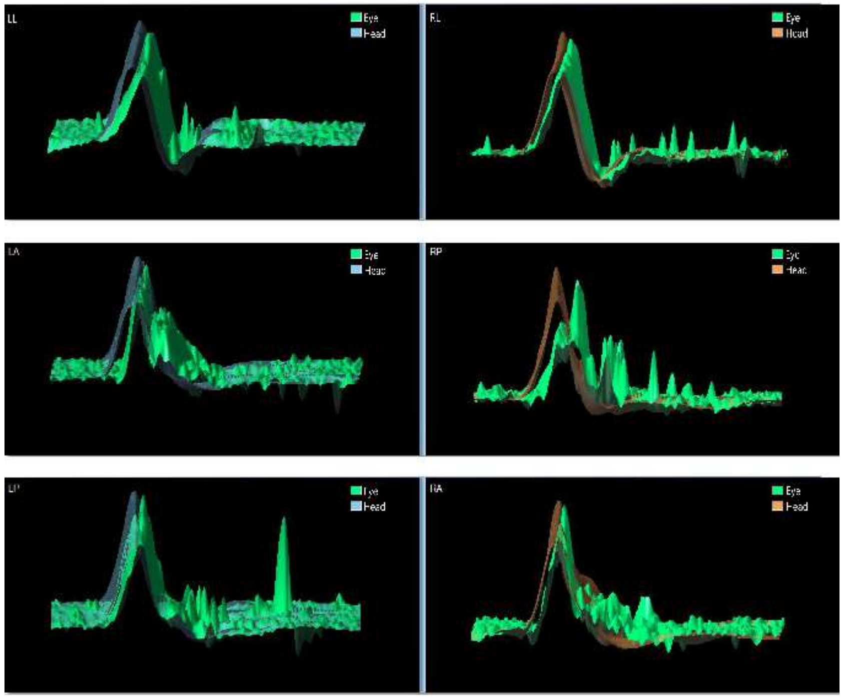
Results Study 2 (3/3)

In the pilot with the strongest reduction, covert and overt saccades are visible in the vertical semicircular canals after >2000h of flight and exposure to F/A 18

<300 h; no aerobatic; no F/A 18



>2000 h; aerobatic; F/A 18



Conclusions

Our findings suggest:

1. rVOR gain to head impulses decreases in pilots exposed to
   - high number of flight-hours (>2000 h)

   AND
   - tactical, high-performance flight condition

2. This decrease may lead to borderline pathological outcome of clinical vHIT

3. This decrease may reflect an adaptation to aberrant rVOR in flight when focus on cockpit target is needed

Questions?