ORIGINAL ARTICLE

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

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Abstract

Conclusion: There were no changes in the function of the six semicircular canals in active fighter pilots, through the use of the video head impulse test (vHIT). These results suggest that the vestibuloocular reflex (VOR) works well at the high frequencies related to the natural head movements in this population. Objectives/hypothesis: The vestibular function in pilots has been reported as being different from that of other normal subjects. These differences are attributed to adaptation of the vestibuloocular reflex (VOR) or by habituation. These studies were conducted with caloric and/or rotatory tests and were limited to the lateral semicircular canals. The aim of the present study was to verify the occurrence of high frequency changes in the function of the six semicircular canals in active fighter pilots, through the use of the video head impulse test (vHIT). Study design: Cross-sectional design. Methods: The subjects participating in this study were divided in three groups, according to their flight experience. The control group (Group 1) consisted of 20 soldiers with no experience of in-flight training. For the test subjects 14 fighter pilots were selected and divided into two groups. Group 2 included the pilots with 1000–2000 hours of flight experience and Group 3 included pilots with 2001–3000 hours of flight experience. They were all submitted to a video head impulse test and the gains of the six semicircular canals were analysed. Results: There were significantly low gain values (p < 0,013) only in the left posterior semicircular canal in the control group as compared with the subject groups. However, there were no significant differences in gain values between the two groups of the active pilots.

Keywords: Vestibular evaluation, vHIT, fighter pilots

Introduction

Interaction of the vestibular system with other stabilizing visual-vestibular interaction (VVI) systems is essential for the aviator to succeed in the complex visual motions of the flight environment and enhances a flyer’s ability to maintain his situation awareness and spatial orientation [1]. During a flight in a jet or a fighter plane the pilot is submitted to several types of acceleration. In order to maintain an adequate performance during all of these situations, he must rely on six biological systems to stabilize his visual field: VOR, OKN, convergence, saccades, fixation, and pursuit. Therefore, for flyers, different VVI functions are prioritized, depending on the operational needs. The Visual-Vestibular Ocular Reflex (VOR) is required to track a stationary (earth fixed) target while turning. Pursuit (slow eye movement) is essential to track and identify slowly moving objects and saccades (fast eye movements) are
necessary to acquire objects detected in the peripheral visual field. Visually-induced optokinetic nystagmus (OKN) occurs in a moving visual background, contributing to optical flow and the sense of speed over terrain. Suppression of the Vestibular Ocular Reflex (VOR) is required when tracking a head fixed target (such as a helmet mounted visual display) while turning. VOR gain and retinal instability may be significantly altered by viewing a movable telescopic sight (optical targeting device). Moreover, the flight environment provides information in a different context, which includes visual-vestibular mismatches [2], changes of gravity [3], and angular or linear acceleration [4]. Thus, it is likely that there are differences between the vestibular functions of pilots and non-pilots, and several studies have investigated these differences [5,6]. The authors interpreted their results as habituation or adaptation acquired by means of previous flight experience.

The VOR is an old phylogenetic brainstem reflex. It can change, nevertheless, to adjust to prevailing environmental circumstances. These changes may occur immediately or after several days to weeks, and are classified as habituation and/or adaptation.

Although vision is the stimulus for many adaptive changes of VOR performance, the VOR may also show habituation, a reduction of response after repetitive stimulation in complete darkness. Habituation is most evident after repeated constant-velocity or low-frequency continuous oscillations [7].

The VOR must be continuously calibrated by short- and long-term adaptations to correct for many errors induced by visual or vestibular changes. These errors are perceived by vision, which re-adjusts the VOR by a process called motor learning or VOR adaptation [7].

Jager and Henn [8] reported that habituation always occurs at a stimulus frequency below 0.1 Hz, resulting in a decrease of the VOR gain. More recently, Ahn [9] reported that VOR gain increases in non-pilots, but not in pilots, during slow harmonic acceleration test at 0.16 Hz after four successive velocity step tests. Lee et al. [10] demonstrated significantly higher gain values in all active pilot groups as compared with the control group at the frequencies above 0.04 Hz induced by sinusoidal harmonic acceleration, suggesting that those results might be caused by adaptation related to VOR plasticity rather than habituation.

In most of these studies, only the lateral semicircular canals were assessed, either by caloric or rotatory tests. These tests, however, are limited to low frequency stimuli.

This study is concerned with the Head Impulse test, a procedure that employs physiological stimuli and can identify high frequency responses from all six semicircular canals. There are no references of studies performed with high frequency stimuli or studies of responses from the vertical canals.

The Head Impulse test was described by Halmagyi and Curthoys [11] in 1988. They stated that, in a high percentage of cases, short and quick head movements would induce saccadic eye movements and demonstrated that these saccades resulted from the stimulation of phasic receptor cells in the crista of one of the lateral semicircular canals, the contralateral one being inhibited by the quick movement, of the order of 200 °/s. These physiological principles have been confirmed by other investigators [12].

Halmagyi et al. [13] verified that with the patient’s head in different positions it was possible to investigate each of the six semicircular canals. Magnusson et al. [14], in 2002, demonstrated that it was possible to improve the reliability and sensitivity of the test using videonystagmoscopy. The Video Head Impulse Test (vHIT) is much easier to interpret, particularly in relation to the vertical canals.

The aim of this present study was to verify the occurrence of changes in the function of the six semicircular canals of active fighter pilots, using high frequency stimulation through the use of the video head impulse test (vHIT). The method has been published in detail [15]. This study was approved by the Ethics Committee of the Albert Einstein Hospital in São Paulo (CAAE: 06137012.3.0000.0071) and the Brazilian Lutheran University (ULBRA RS) in Canoas (CAEE 06137012.3.2002.5349).

Materials and method

This study was conducted on 34 healthy male subjects serving as soldiers in the Brazilian Air Force (FAB).

Twenty of these subjects (Group I – control) had no experience of in-flight training; their mean age was 20.75 ± 1.37 years.

Fourteen subjects had a flight experience of 1000–3000 h of flight time; their mean age was 32.93 ± 4.39 years. These were divided into two groups. Eight subjects had 1000–2000 h of flight experience – Group 2; the remaining six subjects had 2001–3000 h of flight experience – Group 3.

All of the subjects volunteered for the present study and signed an informed consent. Medical histories and physical examinations established that all had normal visual, normal vestibular function, and normal neurologic tests.

The subjects were instructed to sit in front of a laser dot on a screen at a distance of ~ 1.50 m in a dimly lit room and were instructed to look at the target. For testing each semicircular canal, ~ 20 head impulses in
each direction were manually delivered by the experimenter with random timing and direction. Peak head velocity of the impulses ranged from 50–250 °/s (acceleration = 750 to 5000 °/s²; amplitude = 5–20°). The position of the right eye was recorded at 250 Hz sampling rate using video-oculography.

Vertical head impulses were delivered by the clinician when the subject was seated with his body facing the target but his head turned ~ 35° to the left (for testing in the plane of the right anterior and left posterior semicircular canals) or to the right (for testing in the plane of the left anterior and right posterior semicircular canals).

Eye position was calculated using a pupil detection method based on a center-of-gravity algorithm written in LabVIEW (National Instruments, Austin, TX). Eye position was differentiated with a 2-point differentiator and low pass filter (0–30 Hz bandwidth) to obtain eye velocity. Head impulses were automatically selected and aligned to peak head acceleration with custom software written in LabVIEW. Trials with blinks and outliers were automatically excluded based on an envelope around the expected eye velocity response. The vestibular performance was calculated by the measurements of the vestibuloocular reflex (VOR), the gain of which was obtained by dividing the eye velocity by the head velocity.

Statistical calculations were performed with PAWS version 18 software, using the two-sample T-test to analyze the VOR values.

**Results**

The effects of flight time on vestibular function were evaluated in control subjects and in all active fighter pilots. There were significantly low gain values (*) only in the left posterior semicircular canal in the control group as compared with the subject groups (Groups 2 and 3 together). Table I shows the statistical data for these groups.

There were no significant gain differences among the active pilots with different hours of flying time, for any of the six semicircular canals. Table II shows the corresponding statistical data.

In active pilots a significant asymmetry was seen in the gains of the right semicircular canals in relation to the left ones. In the control group there was a significant asymmetry in the gains of the right and anterior semicircular canals in relation to the left ones, but no significant difference for the right posterior semicircular canals. Table III shows the corresponding statistical data.

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

<table>
<thead>
<tr>
<th>Canals</th>
<th>Control Group</th>
<th>Groups 2 + 3</th>
<th>p-values*</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>GLL</td>
<td>0.94</td>
<td>0.05</td>
<td>0.93</td>
</tr>
<tr>
<td>GRL</td>
<td>0.99</td>
<td>0.06</td>
<td>1.02</td>
</tr>
<tr>
<td>GLA</td>
<td>0.91</td>
<td>0.06</td>
<td>0.91</td>
</tr>
<tr>
<td>GLP</td>
<td>0.98</td>
<td>0.08</td>
<td>0.91</td>
</tr>
<tr>
<td>GRA</td>
<td>0.95</td>
<td>0.09</td>
<td>0.93</td>
</tr>
<tr>
<td>GRP</td>
<td>0.96</td>
<td>0.09</td>
<td>0.93</td>
</tr>
</tbody>
</table>

*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.

Table II. VOR gain of the six semicircular canals (Groups 2 (1000–2000 flight hours) × 3 (2001–3000 flight hours)).

<table>
<thead>
<tr>
<th>Canals</th>
<th>Group 2</th>
<th>Group 3</th>
<th>p-values</th>
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<tbody>
<tr>
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</tr>
<tr>
<td>GRL</td>
<td>0.98</td>
<td>0.06</td>
<td>1.01</td>
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<tr>
<td>GLA</td>
<td>0.89</td>
<td>0.05</td>
<td>0.94</td>
</tr>
<tr>
<td>GLP</td>
<td>1.01</td>
<td>0.08</td>
<td>0.94</td>
</tr>
<tr>
<td>GRA</td>
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<td>0.07</td>
<td>0.96</td>
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<tr>
<td>GRP</td>
<td>0.96</td>
<td>0.10</td>
<td>0.96</td>
</tr>
</tbody>
</table>

No statistically significant differences by Student’s t test.

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.

Table III. VOR gain of the six canals for Group 1 (controls) and Groups 2 and 3.

<table>
<thead>
<tr>
<th>Canals</th>
<th>Groups 2 and 3</th>
<th>Group 1 (controls)</th>
</tr>
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<tbody>
<tr>
<td></td>
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<td>0.94</td>
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<tr>
<td>GRL</td>
<td>0.99</td>
<td>0.06</td>
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<tr>
<td>GLA</td>
<td>0.91*</td>
<td>0.05</td>
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<tr>
<td>GLP</td>
<td>0.98</td>
<td>0.08</td>
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<tr>
<td>GRA</td>
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<td>0.09</td>
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</table>

* Significance associated with multiple comparison of Tukey values for p < 0.05 (reference: GRL).

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.
Discussion

There were no changes in the VOR gain of the pilots compared with the control group except for the left posterior semicircular canal. Further studies are needed to identify the reason for this asymmetry. In view of the small sample, the low VOR gain of the left posterior semicircular canals may be meaningless.

Studies conducted by Lee et al. [10], using a harmonical rotation chair, showed that there were significantly higher gain values in all active pilot group as compared with the control group at frequencies above 0.04 Hz, and in student pilots after flight training, as compared with before training at 0.01, 0.04, and 0.08 Hz. VOR gain tended to increase with increasing test frequency.

The physiological bases of the vHIT show that the image of the target does not leave the foveal area of the retina. The eye must turn in a direction opposite to that of the head with the same amplitude and the same velocity. However, the fact that the velocity of the head exceeds 200 °/s renders the voluntary smooth pursuit system, as well as the optokinetic reflex, inoperative in the process of stabilization of the image. Consequently, the effectiveness of the maintenance of the image of the target on the fovea during the impulse test depends exclusively on the gain of the VOR. The vestibular system operates over a wider range of frequencies, with otoliths contributing to stability in the lower frequencies (<1 Hz) and the semicircular canals contributing in the higher frequencies (up to 5 Hz). Another characteristic of the movements of the impulse test is that they stimulate the phasic cells located at the apex of the crista ampullaris, while the rotation tests, with speeds usually lower than 100 °/s, stimulate especially the tonic cells located at the base of the cupula.

There were no significant gain differences among the active pilots for any of the semicircular canals tested, regardless of the flying time. This suggests that, when VOR approaches unity gain at high frequencies, the adaptive capability may have a limited range. The same results were found in studies in rotation test among active pilots with no further functional changes in the VOR gain after achieving a certain adaptive level [10].

VOR gains are higher in the right superior semicircular canal than in the left lateral semicircular canal in all groups. The probable reason is that the data are recorded only from the right eye, which may render them slightly biased [16]. Further studies will be necessary to confirm these results, since no previous data were available on responses to high frequency stimulation, and the vertical semicircular canals could not be individually tested until the development of the vHIT.

Conclusion

These results suggest that VOR works well at the high frequencies contained in the natural head movements induced by vHIT and do not suggest adaptation or habituation related to VOR plasticity in active jet pilots when subject to high frequency stimulations. It must be noted that these results show responses of the vertical canals that had not been previously investigated. Further studies are needed to acquire more information regarding vestibular adaptation and habituation in pilots.

Declaration of Interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

References