



A Case Study

**NEURO-OTOLOGIC TEST CENTER EVALUATION
IN MILD TRAUMATIC BRAIN INJURY**

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Abstract:

Introduction: Opportunities to evaluate neuro-otologic test data on a subject prior to and following a mild traumatic brain injury (mTBI) are rare. An exception is if there is data collected on a pre m-TBI subject as part of a normative data collection program and or product development testing. This case report involves just such a unique mix of circumstances where data had been collected on a normal test subject who later suffered an mTBI.

Methods and Materials: Prior to the subject's mTBI, Optokinetic (OKN), Spontaneous, Saccade, Horizontal and Vertical Gaze, Subjective Visual Vertical (SVV) and Subjective Visual Horizontal (SVH), Head Thrust Test (HTT), and Sinusoidal Harmonic Acceleration (SHA) data was collected during product development testing. These tests were repeated numerous times during the six months following the injury.

Results: All results prior to the accident were within normal parameters. Following the mTBI, all results were abnormal, suggesting both peripheral and central vestibular dysfunction. At six months following the mTBI event, the subject's results for HTT, and SHA tests remained abnormal.

Conclusions: The findings in this report underscore the potential benefits of a more aggressive neuro-otologic evaluation of patients with mTBI for both clinical investigation, and clinical management.

BACKGROUND

Of the estimated 1.5 million traumatic brain injuries occurring annually (1), approximately 75-90% are mild traumatic brain injury (mTBI) (1, 2). Mild traumatic brain injury has been defined (1, 3) as a blunt trauma induced physiological disruption of brain function, as manifested by a least one of the following: any period of loss of consciousness lasting thirty minutes or less; any loss of memory for events immediately before or after the accident; any alteration in mental state at the time of the accident (eg, feeling dazed, disoriented, or confused); and/or focal neurological deficit(s) that may or may not be transient. The definition of mTBI does not include posttraumatic amnesia of greater than 24 hours, an initial Glasgow Coma Scale (GCS) of less than 12 within thirty minutes following injury and/ or loss of consciousness of greater than thirty minutes. Symptoms such as headache, dizziness, irritability, fatigue, or poor concentration, when identified soon after injury, can support the diagnosis of mTBI, but cannot be used to make the diagnosis in the absence of loss of consciousness or altered consciousness (3).

The mTBI patient commonly complains of somatic, cognitive and behavioral problems following injury (4-11), symptoms that can persist for several months (12). As summarized in the National Center for Injury Prevention and Control's *Report to Congress on Mild Traumatic Brain Injury in the United States: Steps to Prevent a Serious Public Health Problem* (1), lost time from work can be substantial, and rates of unemployment in those that have suffered mild traumatic brain injury is markedly higher than the general population. The economic burden from mild traumatic brain injury is reportedly \$16.7 billion per year (1).

Neuro Kinetics, Inc (NKI) manufactures the I-Portal® NOTC (Neuro-Otologic Test Center). The I-Portal NOTC has the capacity to execute a full battery of ocular motor and motion stimulus tests while measuring the response of the eyes at over 100 hz. The I-Portal NOTC technology executes the same battery of tests traditionally used in the diagnosis of vestibular and neurological disorders. Most of the NKI employees and a number of outside test subjects have been tested in the I-Portal NOTC as part of NKI's product development process allowing for the collection of a sizable set of normal subject data.

The following case report is based on one of those product development test subjects who later suffered an mTBI.

CASE REPORT

A 47-year-old male NKI employee was in a bicycle accident that resulted in a mild closed head injury on April 7, 2008. At the time of the injury, he was physically very active and in general good health. The accident occurred while traveling at approximately 20 miles per hour when the front wheel of his bicycle locked as a result of a flat tire, catapulting him over the handle bars resulting in an impact to his head and left shoulder. The subject was wearing a Bell Avalanche bicycle helmet, purchased in the late 90's and meeting the safety standard of the time (13). The helmet incurred a midline break from the incident. The patient experienced no loss of consciousness, but did have an altered mental state immediately after the accident that he described as "seeing stars" and "having his bell rung".

The patient immediately sought care at a local hospital and was evaluated in the emergency room. He presented with chief complaints of cephalgia and neck pain. A head CAT scan without contrast did not reveal any insult. The treating physician diagnosed the patient with a mild head injury without concussion. Post discharge from the emergency room, the patient experienced symptoms of diplopia and excessive fatigue which gradually improved during the following six months, but did not fully resolve.

The subject, tested at NKI prior to the mTBI on several occasions for the purposes of product development, had no history of prior head or vestibular injury before this incident and all previous I-Portal NOTC test data collected was within normal limits. Post mTBI, the subject was tested regularly with I-Portal NOTC evaluation.

METHODS AND MATERIALS

All tests were performed utilizing the I-Portal NOTC and in the manner stated by the User Manual (14) with the exception of the Head Thrust Test (HTT).

The HTT is a well defined standard neuro-otological test being adapted to a passive head-on-body (spine-in-alignment) test using the I-Portal NOTC. This subject was run using 385 ft lb servo direct torque motor at an acceleration of 750 deg/sec². Each HTT set included 10 clockwise (CW; rightward referenced to patient) and 10 counter-clockwise (CCW; leftward referenced to patient) randomized trials. During testing, both horizontal and vertical eye data compared to chair velocity were collected. Each trial was analyzed separately; cycle(s) contaminated by artifacts (blinks, head slippage, unexpected saccades) were removed. Latencies were removed for all cycles. All accepted cycles in the CW direction were averaged and all accepted cycles in the CCW direction were averaged for individual CW and CCW gain calculations.

The patient had undergone Optokinetic (OKN), Spontaneous, Horizontal and Vertical Gaze, Saccade, Subjective Visual Vertical (SVV) and Subjective Visual Horizontal (SVH), Head Thrust Test (HTT), and Sinusoidal Harmonic Acceleration (SHA) testing prior to the mTBI injury as part of the product development process. After the injury occurred, these tests were repeated for six months following injury, at the intervals shown in Table 1.

The subject continued to be tested post mTBI as part of product development testing. The subject was tested randomly multiple times using standard vestibular testing protocols with the I-Portal NOTC platform. Not all tests were run in all sessions due to subject discomfort resulting from diplopia and a false sense of target motion.

RESULTS

Throughout the testing there was a consistent pattern showing an initial diminution in vestibular response, with gradual improvement over the several months.

Optokinetics

Optokinetics (OKN) testing was performed at 20 deg/sec, 40 deg/sec and 60 deg/sec CW and CCW. The results are detailed in figures 1-3. OKN gains and symmetry pre-injury were within normal limits. OKN gain post mTBI was depressed for all conditions with the CCW direction having greater reduction than CW. Twenty degrees per second OKN recovered the most quickly for CW to pre-injury levels at a one week post injury but relapsed until two months post injury. Counter-clockwise results at 20 deg/sec followed a waxing and waning pattern until one month post injury when eye velocity gain continued to improve until pre-injury levels were attained at 2.5 months. Optokinetic testing at 40 and 60 deg/sec rotation followed a pattern similar pattern of

recovery. Nearly all gain results improved on repeat testing over time. Significant asymmetry was noted at 20 deg/sec for the first 3 weeks and at 40 deg/sec at 4 days post injury and at 60 deg/sec slightly over one month post injury.

Spontaneous nystagmus, Horizontal and Vertical Gaze

No spontaneous, or gaze nystagmus was present in pre-injury testing. Post mTBI, center gaze position spontaneous nystagmus (vision denied) of 0.45-1.0 deg/sec left beating was noted. Spontaneous nystagmus was left beating in gaze left and right and right beating in gaze up and gaze down, with gaze up being the most prominent (2.67 deg/sec). There was no nystagmus with vision present. By three weeks post injury the spontaneous nystagmus had resolved (figure 4).

Subjective Visual Vertical (SVV) and Subjective Visual Horizontal (SVH)

Subjective Visual Vertical (0.4 deg) and SVH (0.3 deg) pre-injury were within normal limits. Post mTBI both SVV and SVH rotated toward the patient's right side at 4.45 and 3.6 degrees respectively. The degree of rotation decreased steadily until 8 weeks post injury where SVV and SVH returned to normal (figure 5). Results returned to near initial test results at 2.5 months post injury.

Head Thrust Test (HTT)

NKI is developing a new "Head Thrust" test (HTT) using the high torque rotary motor incorporated in its I-Portal NOTC-C system to run a test at accelerations of up to 2000 degrees per second squared with the spine in alignment, head-on-body rotation. As part of the product and test development, the subject was tested at 750 deg/sec². Each HTT set included 10 clockwise (CW; rightward referenced to patient) and 10 counter-clockwise (CCW; leftward referenced to patient) randomized trials.

Before the accident, left and right gains were approximately one (1). While a normative data base has yet to be collected for this new test, a gain of one (1) is the value logically expected for a normal subject. Gains decreased to 0.81 for CW HTT and 0.51 for CCW HTT at initial testing. At three months post injury gains were still lower CCW than before the accident (figure 6).

Saccades

During saccade testing, peak eye velocity (deg/sec), percent accuracy (main saccade only), percent overall accuracy, (sum of main and additional corrective saccades), and latency (sec), were measured separately for left (figure 7) and right eye (figure 8) moving to the left or right. It was observed that latency, accuracy and overall accuracy did not change significantly before and after accident but peak eye velocity became abnormally low bilaterally and bi-directionally.

Sinusoidal Harmonic Acceleration

The subject underwent sinusoidal harmonic acceleration chair rotation testing seven times over a six month period. Testing frequencies were 0.01Hz, 0.02Hz, 0.04Hz, 0.08Hz, 0.16Hz, 0.32Hz, 0.64Hz, 1.28Hz and sometimes 1.5Hz at a velocity of 60 deg/sec. Analyses were based on the multivariate statistics model put forth by Dimitri et al (15). Out of 7 series of tests, 5 showed abnormal overall low gain (4/25/2008, 6/4/2008, 6/23/2008, 7/10/2008, and 10/8/2008) but only one showed overall abnormal asymmetry (4/15/2008).

DISCUSSION

Mild Traumatic Brain Injury is viewed as a major health concern in children and young adults (1) and for our soldiers returning from Iraq and Afghanistan. The definition of what is considered an mTBI is evolving, and as stated earlier, the impact on the individual and the wider society as a whole is significant. The mechanism of dysfunction is thought related to diffuse axonal injury that occurs from the sustained acceleration and deceleration inertial forces associated with mTBI (16), and rarely are findings noted on computed tomography or magnetic resonance imaging. Microscopic findings reveal the Wallerian-type axonal degeneration. Data from motor vehicles collisions indicate that the threshold average velocity for severe diffuse axonal injury is 15 miles/hr (17), a speed that can easily be reproduced in sports or other activities such as bicycling, as in this case study.

Reports of vestibular testing following mild traumatic brain injury are intriguing, but variations in the definition of mTBI and in the vestibular testing performed makes interpretation challenging. Gottshall (18) used active Dynamic Visual Acuity Testing (DVAT) in combination with the Dizziness Handicap Index (DHI) as an outcome measure in mTBI subjects, and concluded that the combination was useful in assisting providers with recommendations for activities such as returning to work. However, further work from the same author suggests that acute vestibular dysfunction as measured with active DVAT and Computerized Dynamic Posturography (CDP) was not an independent predictor of work status at twelve months (19). Others (20) have raised concerns that the results of active DVAT can give false negative findings, as active head movements can generate both compensatory and anticipatory saccades.

Marzo (21) found that of 12 mTBI patients tested, five had abnormalities noted on CDP, typically condition 5 and 6, three had caloric weakness and two had central findings on electronystagmography. Of the six who underwent rotary chair testing, none were abnormal. Hoffer (22) also performed post mTBI vestibular testing, and used it to help define three posttraumatic classifications: positional vertigo which did not have abnormality on vestibular testing; migraine associated dizziness (PTMAD) which had vestibulo-ocular reflex (VOR) gain, phase, or symmetry abnormalities, high frequency VOR gain abnormalities, and normal CDP; spatial disorientation which had VOR gain, phase, or symmetry abnormalities, high frequency VOR gain abnormalities, and abnormal CDP, and central findings on visual vestibulo-ocular reflex or visual fixation abnormalities or videonystagmography (VNG) testing. Both the PTMAD and the spatial disorientation mTBI groups had a mid frequency (0.32 and 0.64 Hz) phase shift on SHA, with several in both groups showing an abnormally low gain in the mid frequency range. After 6 to 8 weeks of vestibular therapy, 84% of those with PTMAD had improvement in VOR, only 27% in the spatial disorientation mTBI group.

At 6 months post injury, the subject had continued complaints of fatigue and diplopia, which are well documented chronic complaints typical in mTBI(1). Initially, the subject had significant changes in OKN, Saccades, Spontaneous, HTT, SHA, and SVV/SVH testing, suggestive of both central and peripheral injuries. Over time, CW OKN returned to baseline and the spontaneous nystagmus resolved. However, SVV and SVH, tests of otolith function OKN, HTT, and SHA at six months had not returned to baseline, supporting the possibility of persistent peripheral and central deficits. While a case report,

the findings with this subject support a more aggressive vestibular evaluation of patients with mTBI for both the purpose of clinical investigation, and clinical management.

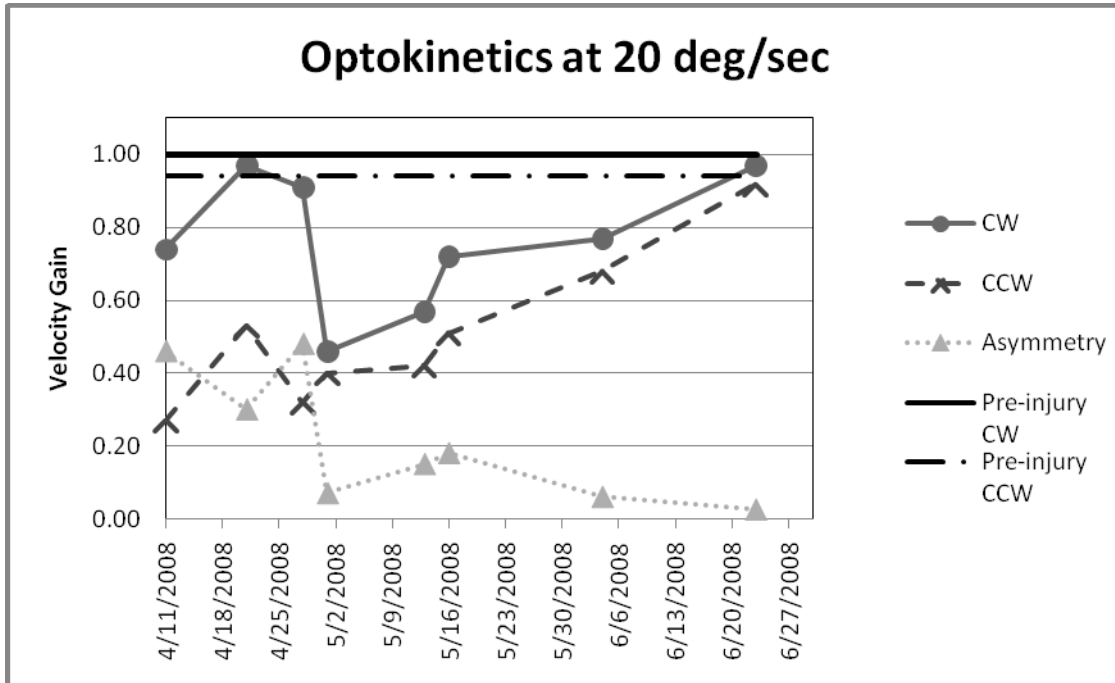
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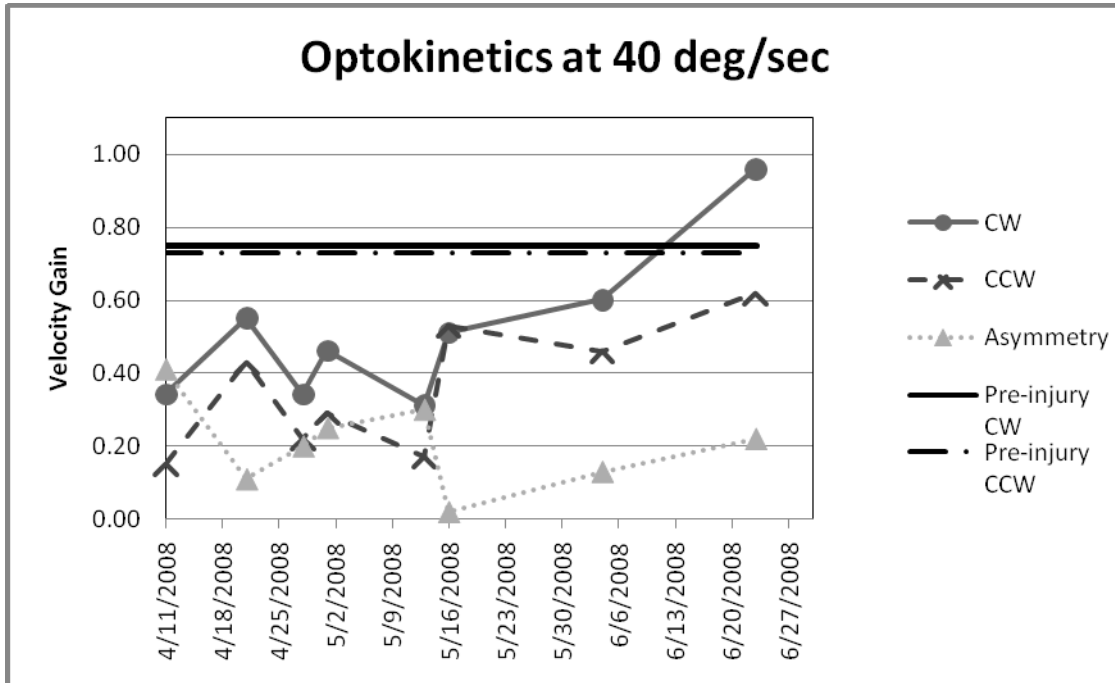
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Figure 1. OKN (20 deg/sec) Velocity Gain



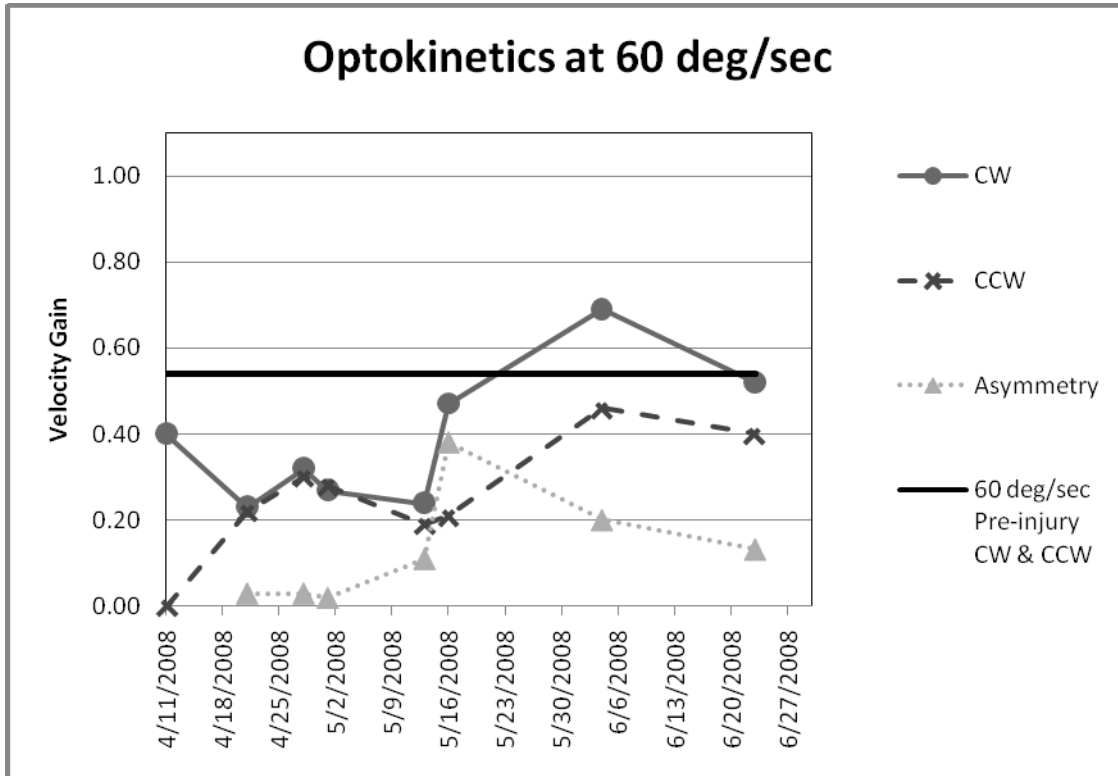
Four days after the accident the subject's OKN gain diminished for CCW rotation from 0.94 before injury to 0.3 and from 1 to 0.74 for CW rotation with asymmetry increased from 3% to 48%. Approximately 2 weeks after injury gain on CCW increased and CW decreased until asymmetry became less than 20%. Gain on both sides then started to increase with CW continuing to lead CCW. Eight weeks after accident OKN gain became close to pre-accident level (0.96 vs. 1.0 CW, 4% below pre-accident testing, and 0.77 vs. 0.94 CCW, 18% below pre-accident testing).

Figure 2. OKN (40 deg/sec) Velocity Gain



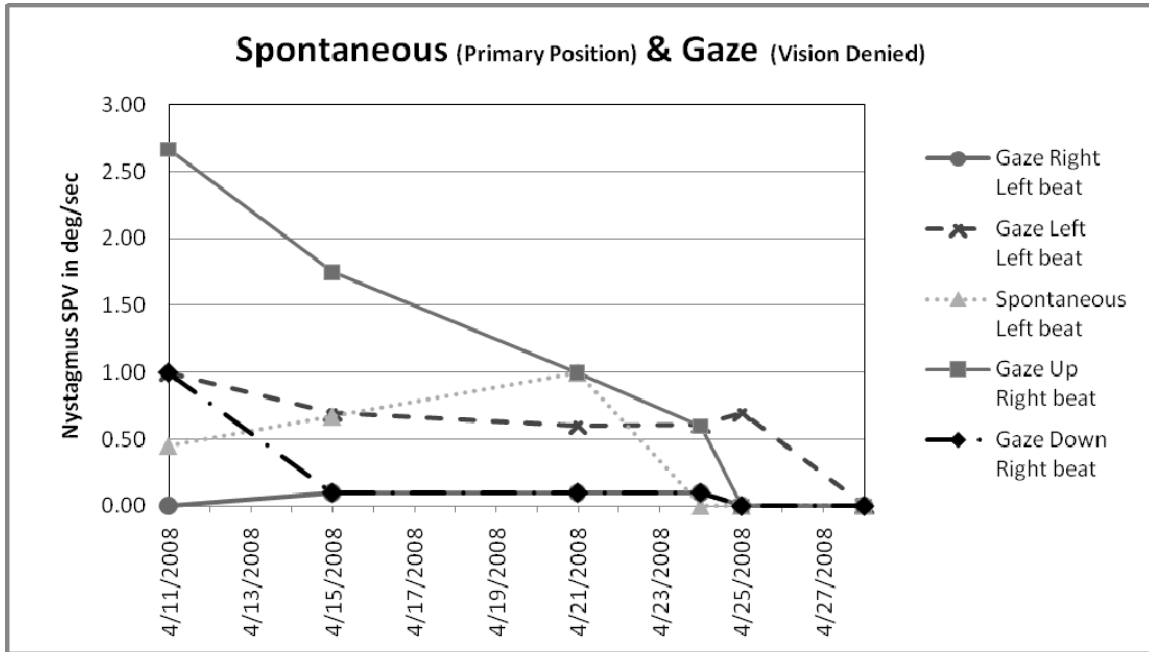
The subject's OKN gain diminished on CW rotation from 0.75 before injury to 0.34 (4 days after accident) and from 0.73 to 0.15 on CCW rotation. Asymmetry 4 days after accident was 41%. The trend shows that after approximately 4 weeks gain on CCW started to increase and follow CW. Eleven weeks after accident gain normalized (0.75 versus 0.75 on CW and 0.62 versus 0.73 on CCW, 15% below pre-injury testing).

Figure 3. OKN (60 deg/sec) Velocity Gain



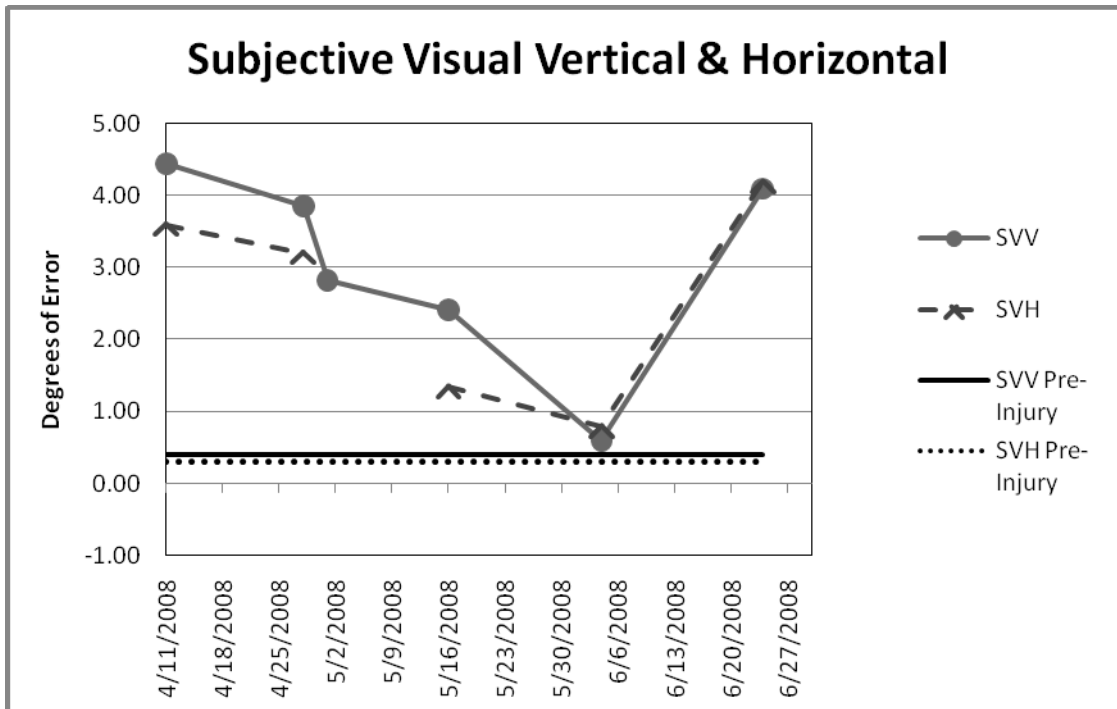
Four days after accident subject's OKN gain diminished on CW rotation from 0.54 before injury to 0.4 and there was no response from CCW. The first response from CCW was noted after 2 weeks and was 0.23 versus 0.53 before accident. At that time the CW gain decreased to 0.2. Both directions continued to increase, with the CW direction leading the CCW.

Figure 4. Spontaneous Nystagmus, Horizontal and Vertical Gaze



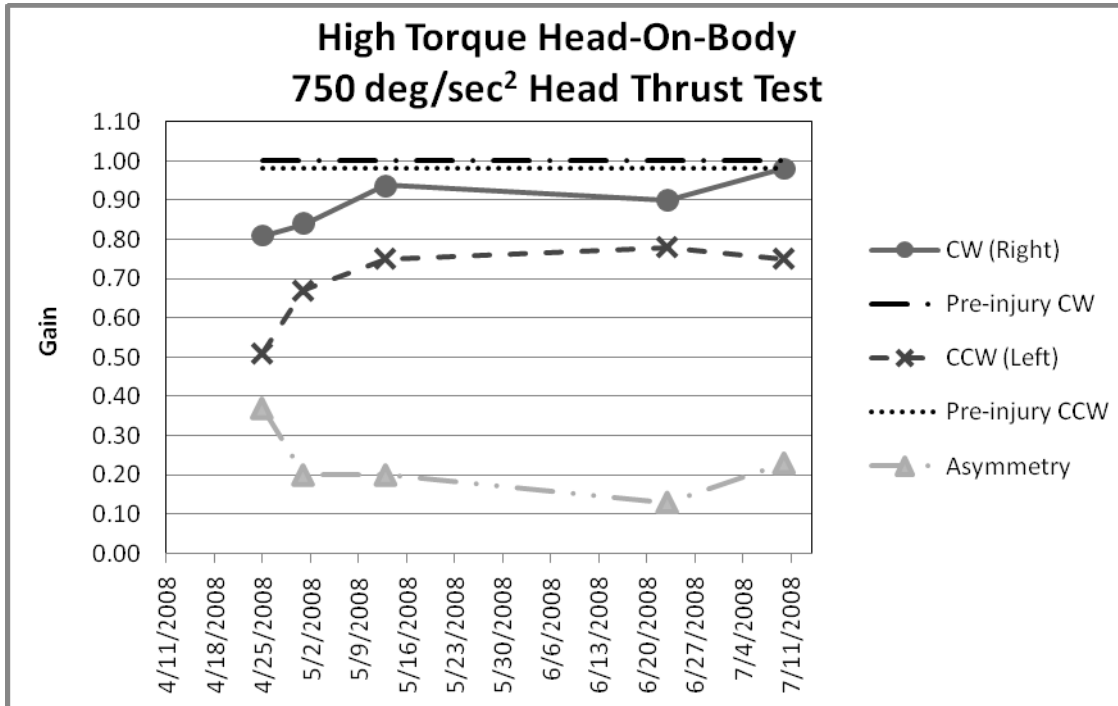
Four days after accident it was recorded that subject had spontaneous left beating nystagmus in primary position and gaze right/left (vision denied) and right beating nystagmus in gaze up/down. Maximum average slow phase velocity of 2.27 deg/sec during gaze up. No beats of spontaneous nystagmus had been observed before accident. By three weeks after accident, the spontaneous nystagmus resolved.

Figure 5. Subjective Visual Vertical (SVV) and Subjective Visual Horizontal (SVH)



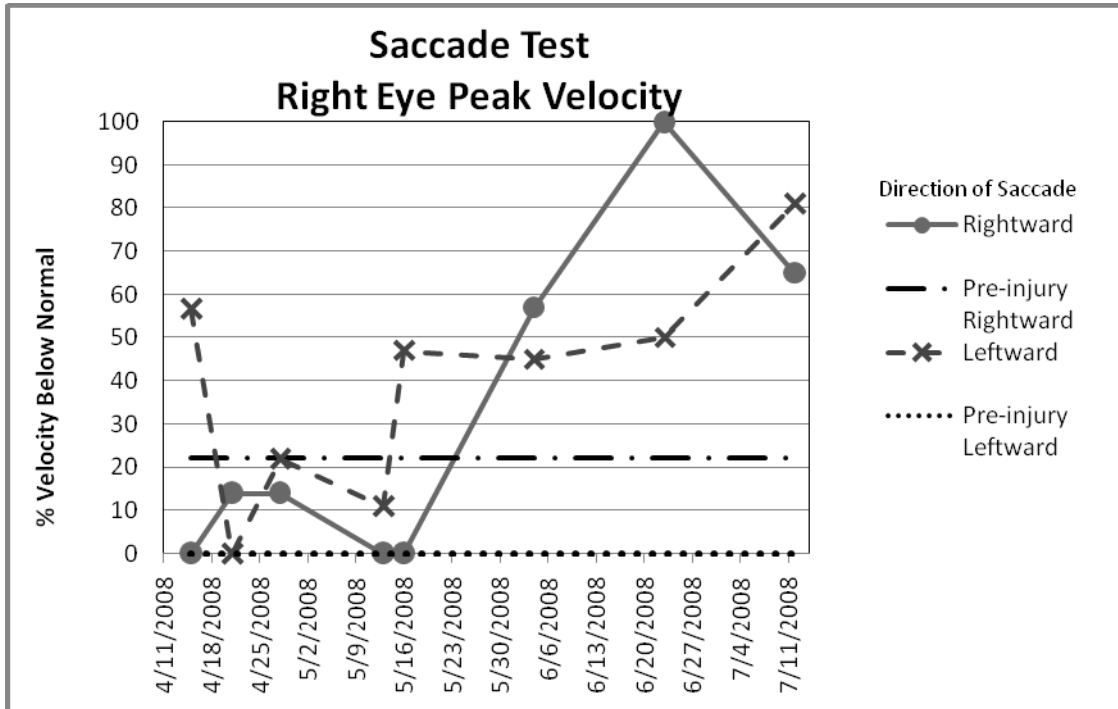
Four days after accident it was recorded that result of SVV and SVH testing became abnormal: SVV increased from -0.4 deg before accident to +4.45 deg and SVH increased from -0.3 deg before accident to +3.6 deg. By eight weeks after accident SVV and SVH returned to normal.

Figure 6. **Head Thrust Test**



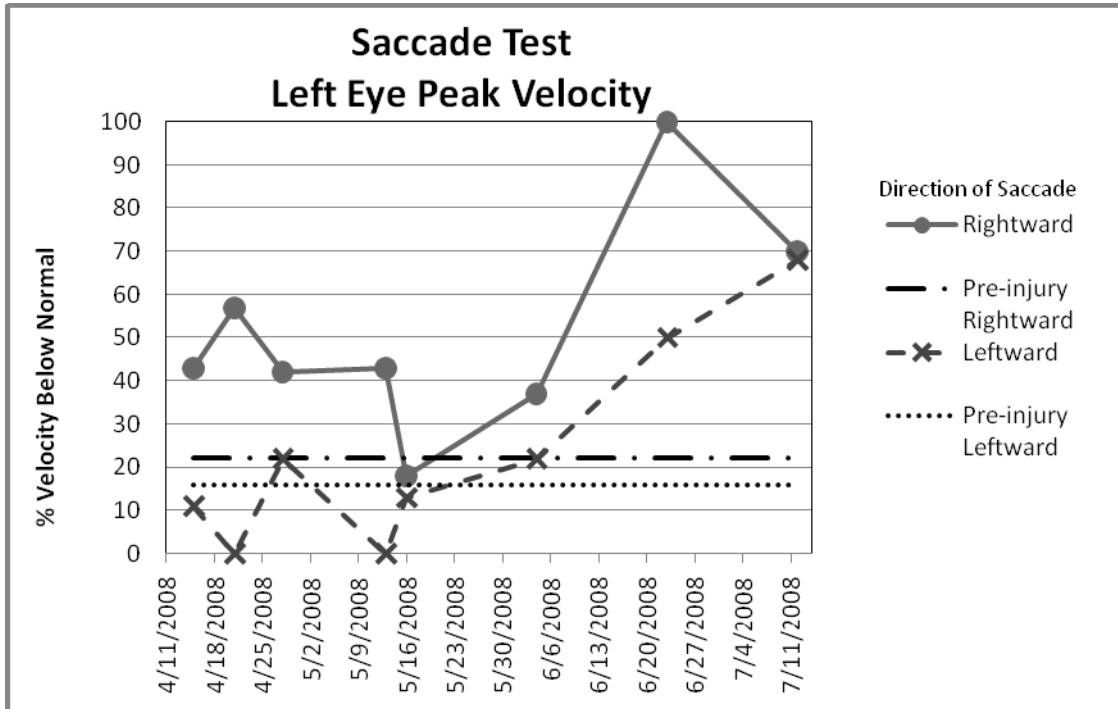
Head Thrust Test at approximately 2 weeks after accident showed reduced gain for CCW (referenced to patient) thrusts (0.51) and CW (0.81) with asymmetry of 0.37. Before the accident CCW and CW gain was near 1.0. Four weeks after accident, asymmetry remained with CCW gain reduced compared to CW gain. Overall gains at six months were still lower than before accident.

Figure 7. **Percentage of Peak Velocity for Right Eye Horizontal Saccades**



At 8 weeks after accident, percentage of peak eye velocity below the normal range was increased from 0% before accident to 66% for right eye moving right and from 22% to 81% for right eye moving left.

Figure 8. Percentage of Peak Velocity for Left Eye Horizontal Saccades



At 8 weeks after accident, percentage of peak eye velocity below the normal range was increased from 16% to 68% for left eye moving left and from 22% to 70% for left eye moving right.

Table 1. Date, Time and Tests Completed

Date	Time	OKN	SN,GHV	SVV,SVH	HTT	L S	R S	SHA
4/11/2008	0847	*	*	*				
4/15/2008	1259	*	*			*	*	*
4/21/2008	1228	*	*			*	*	
4/24/2008	0845	*	*					
4/25/2008	0826	*	*		*			*
4/28/2008	0845	*	*	*	*	*	*	
5/01/2008	1122	*	*	*	*			
5/13/2008	0913	*	*		*	*	*	
5/16/2008	1237	*	*	*	*	*	*	*
6/3/2008	1439		*	*				
6/4/2008	0918	*			*	*	*	*
6/23/2008	0853	*			*	*	*	*
7/10/2008	1128				*	*	*	*

Time recorded in 24 hour format at start of test session. OKN=optokinetics; SN, GHV= spontaneous nystagmus, horizontal and vertical gaze (vision denied); SVV, SVH= subjective visual vertical and subjective visual horizontal testing; HTT= head thrust test, L S= left eye saccade testing; R S= right eye saccade testing; SHA= sinusoidal harmonic acceleration testing.