Cervicocephalic Kinesthetic Sensibility, Active Range of Cervical Motion, and Oculomotor Function in Patients With Whiplash Injury

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ABSTRACT. Heikkilä HV, Wenngren B-I. Cervicocephalic kinesthetic sensibility, active range of cervical motion, and oculomotor function in patients with whiplash injury. Arch Phys Med Rehabil 1998;79:1089-94.

Objective: To investigate cervicocephalic kinesthetic sensibility, active range of cervical motion, and oculomotor function in patients with whiplash injury.

Design: A 2-year review of consecutive patients admitted to the emergency unit after whiplash injury.

Setting: An otorhinolaryngology department.

Patients and Subjects: Twenty-seven consecutive patients with diagnosed whiplash injury (14 men and 13 women, mean age, 33.8yrs [range, 18 to 66yrs]). The controls were healthy subjects without a history of whiplash injury.

Main Outcome Measures: Oculomotor function was tested at 2 months and at 2 years after whiplash injury. The ability to appreciate both movement and head position was studied. Active range of cervical motion was measured. Subjective intensity of neck pain and major medical symptoms were recorded.

Results: Active head repositioning was significantly less precise in the whiplash subjects than in the control group. Failures in oculomotor functions were observed in 62% of subjects. Significant correlations occurred between smooth pursuit tests and active cervical range of motion. Correlations also were established between the oculomotor test and the kinesthetic sensibility test.

Conclusion: The results suggest that restricted cervical movements and changes in the quality of proprioceptive information from the cervical spine region affect voluntary eye movements. A flexion/extension injury to the neck may result in dysfunction of the proprioceptive system. Oculomotor dysfunction after neck trauma might be related to cervical afferent input disturbances.

WHIPLASH INJURIES are characterized by a sudden positive or negative acceleration of the trunk with hyperextension, hyperflexion, or lateroversion of the neck. The head is thereby thrown backward, forward, or laterally without being hit externally. Whiplash injuries result in long-term disability, with up to 6% of patients not returning to work after 1 year.[1] The symptoms and complaints following whiplash trauma include neck pain, headache, vertigo, nausea, blurring of vision, dysacusis, fullness of the ear, and various emotional and cognitive disturbances.[2-4]

Oculomotor function tests have been used for detecting lesions affecting structures in the brain stem and cerebellum.[5-7] The smooth pursuit and saccade are eye motility functions with important relay stations in the brain stem and cerebellum.[5-7] Recently, pathologic oculomotor dysfunction was reported in patients with whiplash trauma.[8,9] In some patients with moderate smooth-pursuit abnormalities, oculomotor dysfunction may be explained by involvement of the cervical proprioceptive system.[2,8-10] The pronounced oculomotor dysfunction in some whiplash cases is possibly caused by medullary lesions.[8] Pathologic oculomotor dysfunction, however, has even been reported in patients with chronic primary fibromyalgia with dysesthesia.[10]

Whiplash injuries usually result in neck pain due to myofascial trauma, a finding that has been documented in both animal and human studies. It is likely that proprioception is primarily involved, either by lesioning or functional impairment of muscular and articular receptors, or by alteration in afferent integration and tuning.[11-14] It is probable that cervicocephalic kinesthesia is linked to information coming from the extensive muscular and articular proprioceptive system.[14-19] Head orientation in space and with respect to the trunk makes use of visual, vestibular, and cervical proprioceptive cues.[12,14-16,19-22] The neck muscle proprioceptive system can influence the oculomotor and vestibular system.[8,23-25]

Cervical kinesthetic performance is not well described in healthy subjects. Recently, a method of evaluating cervicocephalic kinesthesia was introduced by Revel and colleagues.[26] The test measures the ability to appreciate both movement and the position of the head with respect to the trunk. It involves information from the cervical proprioceptive apparatus and from the vestibular system, but several experimental arguments point primarily to a cervical proprioceptive role.[17] In a previous study patients with chronic dysfunction after a whiplash trauma were significantly less accurate than a control group in their ability to relocate their head in space after an active displacement moving the head away from the reference position.[27] However, the group with whiplash trauma significantly decreased their relocation errors after a 6-week rehabilitation program.

The aim of this study was to investigate kinesthetic and proprioceptive performance after a whiplash trauma in a consecutive series of patients. Correlations between oculomotor test, cervical range of active motion, and cervical kinesthetic sensibility in patients with whiplash injuries were studied.

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Submitted for publication September 17, 1997. Accepted in revised form March 17, 1998.

No commercial party having a direct financial interest in the results of the research supporting this article has or will confer a benefit upon the authors or upon any organization with which the authors are associated.

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0003-9993/98/7909-4651$3.00/0

METHODS

Patient Selection

A consecutive series of 27 patients (14 men, 13 women) who were involved in car accidents 1 to 2 years previously (range, 15 to 26 months) and who were between the ages of 18 and 66 yrs (mean, 38.8yrs) participated in the experiment. All kinds of car impact directions were included. All patients had been investigated at the emergency unit at University Hospital of Northern Sweden for acute neck strain after their traffic accidents.

To be included in the study, patients must have incurred whiplash injury grades II and III, according to the Quebec Task Force Classification on whiplash-associated disorders (WAD). Approximatively 60% of the whiplash patients admitted to the emergency unit had grades I or IV; these patients were excluded from the study. Grade II includes neck complaints and musculoskeletal signs; grade III includes additional signs (decreased or absent deep tendon reflexes, weakness, and sensory deficits). Patients with a head injury, unconsciousness, fracture or dislocation of the cervical spine, or a previous history of neck injury or neck pain, were exluded. At follow-up 2 years after their trauma, 7 subjects (26%) were free from symptoms that could have been related to the trauma. One patient was excluded from this study because of a highly impaired active range of cervical motion and oculomotor test dysfunction pointing to medullary lesion. He was not able to actively move his head more than radius of a few centimeters and, for that reason, the kinesthetic sensibility test was unreliable.

Kinesthetic Sensibility Test

All subjects had their vision occluded by goggles from the start of the experiment. They wore a light helmet firmly tied to the head. A light beam (laser pointer) was affixed to the top of the helmet to point at a target 90cm in front of the subjects. The target was mobile, enabling each subject's reference head position to be accurately located in relation to the target. The target's diameter was 40cm, with concentric circles every centimeter and it was divided into four quadrants cut by two axes intersecting at zero (the horizontal plane in abscissa and vertical plane in ordinate). The subject was seated with a backrest and instructed to face the target straight ahead. Subjects were told to memorize this position to duplicate it after an active movement of maximal amplitude of the head. When the reference position was achieved, the target was placed so that the laser pointer's light beam projected on the zero of the target. After a few seconds of concentration on this position of reference, the subject performed a maximal rotation of the head to the left for approximately 2 seconds, then tried to locate the initial reference position with a maximum of precision without speed instruction. The subject's relocation accuracy (R) was measured in centimeters from the point on which the light beam stopped to the center of the target. The projection on the abscissa and ordinate axes were also measured (X,Y) and each component was assigned either a positive or a negative sign according to its position above or below zero on the corresponding axes. After each trial, the target was repositioned in the initial reference position (light beam on point zero of the target) and no feedback on accuracy was given. Ten trials were undertaken with head rotation to the left (RL, XL, YL), followed by 10 trials to the right (RR, XR, YR). The same experimental procedure was used to study the repositioning of the head from a maximal extension (RE, XE, YE) for 10 trials and from maximal flexion (RF, XF, YF) for 10 trials.

Thirty-nine healthy subjects (24 women, 15 men) from 26 to 53 years of age (mean, 35yrs) volunteered as controls for the kinesthetic sensibility test. All were free of cervical pain or other illnesses and had no history of whiplash injury.

Oculomotor Test

Oculomotor tests were performed for all subjects 2 years after whiplash injury. Horizontal eye movements were recorded by bitemporally placed surface electrodes.[28] The stimulus consisted of a curve-shaped screen with light-emitting diodes. Activation of the diodes and the analysis of the recordings were controlled by computer. The smooth pursuit test consisted of tracking a pendular light diode at a constant speed of 20°/sec and 30°/sec to the right and to the left. Five smooth pursuits at each velocity and direction were stored in the computer, which presented the analysis on a screen and printed the data. Data obtained by this procedure were: (1) the gain (eye velocity/target velocity) of the smooth pursuit and (2) the number of superimposed saccades. The voluntary saccade test was performed by fixation of a light diode on the screen lighted at angles 30°, 40°, and 50° on both sides of the midline. Ten saccades of each type were computer-recorded and analyzed. Estimates were made based on these data: (1) accuracy of the saccades as a percentage of the total amplitude, (2) latency (ie, the reaction time in milliseconds elapsing from the change of the light spot to the start of the eye movement), and (3) peak velocity of the saccade. The control group consisted of 25 healthy individuals, students and collaborators, with a median age of 34yrs (range, 25 to 40yrs), and without a history of a soft-tissue injury of the neck or a head injury.[8]

Active Range of Cervical Motion

A cervical range-of-motion (CROM) instrument with magnetic yokes and compass goniometer to measure cervical motion in the transverse plane (rotation) and two gravity goniometers to measure cervical motion in the sagital plane (flexion-extension) and frontal plane (side-bending) were used. The same CROM instrument was used throughout the study by the same tester, who performed a standardized measurement procedure.[29] Total transverse plane movements (rotation to the right + rotation to the left), sagittal plane movements (flexion + extension), and frontal plane movements (sidebending to the right + sidebending to the left) were recorded in degrees on a scale (range, 0° to 360°).

Statistical Analysis

The variables compared between the control group and the patient group were age, sex, and cervicobrachial pain assessed by a visual analog scale (VAS). Values for the relocation error for each trial (R) and values for horizontal (X) and vertical (Y) repositioning errors were compared in the two groups. The means and standard deviations were calculated for the 10 trials. The percentages of overshooting were compared with a theoretical percentage, using χ^2 test in each group. Student's t test and χ^2 tests were used to compare groups and repeated measurements.

Correlations between age, sex, time passed after trauma, oculomotor test subscales, active range of motion, and the mean of relocating errors were studied using Pearson correlation matrix and its corresponding significance test. Correlations between the oculomotor test and the kinesthetic sensibility test were studied by Spearman correlation matrix and Cronbach's alpha. Values of $p < .05$ were considered statistically significant. All statistical calculations were performed with SPSS[a] on a Macintosh computer.

RESULTS

Kinesthetic Sensibility

Compared with healthy subjects, whiplash subjects showed higher repositioning errors in all directions. The mean relocating error overall was 2.75cm (SD, 1.9) for healthy controls and 3.84cm (SD, 3.2) for whiplash subjects ($p < .001$). Significant differences in repositioning were found between whiplash subjects and controls for all four directions (table 1). Whiplash subjects showed significantly more trials that resulted in reposition error outside a 6-cm radius from the target center. Control group subjects failed the 6-cm radius in 69 of 1,560 trials (4.4%) and whiplash subjects failed 159 of 1,120 trials (14.2%) (χ^2 79.4 [$p < .001$]). Sixteen of the 26 patients with whiplash trauma (62%) showed decreased relocating accuracy (R) in at least one direction, and eight whiplash patients showed decreased accuracy in vertical (Y) or horizontal (X) plane, compared with healthy subjects. In the vertical plane, subjects tended to overshoot the target in flexion and extension.

Whiplash subjects with complaints of dizziness showed a higher repositioning error (R = 4.21cm; SD, 3.09) compared to whiplash subjects without dizziness, (R = 3.78cm; SD, 3.2 [$p < .05$]). Furthermore, whiplash subjects who claimed radiculopathy symptoms (pain irradiation, weakness, sensoric disturbances) showed greater failure in horizontal repositioning (overshooting) compared to whiplash subjects without radiculopathy claims. Mean horizontal error for radiculopathy subjects was 1.04cm (SD, 3.16) compared to −.003cm (SD, 3.4) in controls ($p = .009$) after rotation to the left. A significantly lower range of active motion in the sagittal plane (rotation) occurred for the group with repositioning dysfunction, 132° (SD, 26) compared to 148° (SD, 19) for the group with normal repositioning function ($p < .05$). No other significant differences were found in range of motion for the two groups.

Whiplash subjects who were free of symptoms after injury rated significant lower repositioning errors after rotation to the left (R = 3.4cm; SD 2.9), compared to the subjects who had dysfunction after injury (R = 4.0cm; SD 3.2). No other significant differences were found between whiplash subjects with symptoms after the trauma and symptom-free subjects. Relocation error after whiplash injury was positively correlated with age for whiplash subjects, with a mean error of Spearman $r = .11$ ($p < .001$). The mean age for whiplash subjects with repositioning dysfunction was 42yrs (SD, 17 yrs) compared with 31yrs (SD, 9) for the group with normal repositioning function ($p < .05$). For the control group no correlation was found between age and repositioning error.

Table 1: Accuracy of Head Repositioning After Rotation in Healthy Control Subjects and Whiplash Subjects for All Trials

	Control Mean (SD)	Whiplash Mean (SD)	*p*
Rotation left			
R	2.73 (1.78)	3.36 (2.41)	<.001
X	−0.25 (2.84)	.05 (3.60)	NS
Y	−.28 (1.84)	−.64 (2.28)	<.05
Rotation right			
R	2.85 (2.00)	4.05 (3.4)	<.001
X	.08 (2.93)	.03 (4.81)	NS
Y	−.11 (2.08)	−.47 (2.51)	<.05
Extension			
R	2.85 (1.88)	3.80 (2.86)	<.001
X	−.04 (1.66)	.06 (2.23)	NS
Y	−.25 (3.09)	−.85 (4.25)	<.05
Flexion			
R	2.57 (2.08)	4.14 (3.75)	<.001
X	−.03 (1.53)	.15 (2.06)	NS
Y	−.03 (3.07)	.99 (5.23)	<.01

For control subjects ($n = 39$) there were 390 trials; for whiplash subjects ($n = 26$), there were 260 trials. Values are reported in centimeters.

Table 2: Number of Whiplash Subjects ($n = 26$) Testing Positive for Oculomotor Dysfunction

	Normal	Dysfunctional
Smooth pursuit		
Gain		
20°/sec left	26	0
20°/sec right	24	2
30°/sec left	21	5
30°/sec right	24	2
Superimposed saccades		
20°/sec left	15	11
20°/sec right	2	14
30°/sec left	12	14
30°/sec right	12	14
Saccades		
Accuracy (%)		
Left	17	9
Right	21	5
Latency (msec)		
Left	17	9
Right	16	10
Velocity (°/sec)		
30° Left	19	7
30° Right	11	15
40° Left	18	8
40° Right	17	9
50° Left	18	8
50° Right	17	9

Oculomotor Test

Sixteen whiplash patients (62%) showed pathologic results in one of the smooth pursuit scales and at least one of the saccade scales for two directions at the 2-year follow-up examination (table 2). There was a significant association between oculomotor dysfunction and repositioning dysfunction (Spearman $r = .51, p = .007$; alpha = .68). Significant correlations were observed between smooth pursuit subscales and active range of motion (table 3). Patients with oculomotor dysfunction were less accurate in head repositioning than were persons with normal oculomotor performances (table 4). The mean age for subjects with oculomotor dysfunction was 44yrs (SD, 15 yrs), and for subjects whose tests were normal, 28yrs (SD, 8) ($p < .001$). Oculomotor test results showed significantly more abberations for women than for men 2 years after trauma (table 5). The mean relocating error was 4.18cm (SD, 3.18) for women and 3.60cm (SD, 3.06) for men ($p < .01$).

DISCUSSION

Our study was concerned with the capacity of patients with whiplash injury to relocate the head in space after an active displacement by moving the head away from a reference position. Repositioning dysfunction was present in 62% of subjects with whiplash trauma 2 years after the trauma. Patients with whiplash injury return the head to the reference position with significantly less accuracy than healthy subjects. Some arguments suggest that the neck kinesthetic sensibility is mainly involved in this inaccuracy.[27] The whiplash subjects showed

Table 3: Correlation Coefficients Between Oculomotor Functions and Active Range of Cervical Motion

	Sagittal		Horizontal		Rotational	
	r	*p*	*r*	*p*	*r*	*p*
Smooth pursuits						
Gain						
20°/sec left	.48	*	.56	†	.26	NS
20°/sec right	.47	*	.50	†	.30	NS
30°/sec left	.47	*	.42	*	.25	NS
30°/sec right	.19	NS	.12	NS	.25	NS
Superimposed saccades						
20°/sec left	−.53	†	−.63	‡	−.51	†
20°/sec right	−.55	†	−.45	*	−.30	NS
30°/sec left	−.52	†	−.65	‡	−.38	NS
30°/sec right	−.62	‡	−.63	‡	−.38	NS
Voluntary saccades						
Accuracy						
% Left	.34	NS	.34	NS	.33	NS
% Right	.09	NS	.22	NS	.31	NS
Latency						
Left	−.38	NS	−.43	*	−.31	NS
Right	−.41	*	−.47	*	−.31	NS
Velocity						
30° Left	.20	NS	.13	NS	.04	NS
30° Right	.08	NS	.11	NS	.19	NS
40° Left	.12	NS	.13	NS	.17	NS
40° Right	.14	NS	.15	NS	.18	NS
50° Left	.23	NS	.20	NS	.27	NS
50° Right	0	NS	.06	NS	.12	NS

*$P < .05$.
†$P < .01$.
‡$P < .001$.

less accuracy in vertical plane repositioning movements, which might be explained by the hyperextension/hyperflexion trauma mechanism. However, no significant changes were found for reposition movements in the horizontal plane, implying that the neck proprioceptive receptors in the facet joints are used in this process. Overshooting could indicate a lack of proprioceptive information and a search for additional proprioceptive information coming from stretched antagonist muscles, constituting a type of overshooting by "confirmation." Experimental, clinical, and histologic examinations have verified lesions of the brain stem after whiplash injury.[30-32] Oculomotor dysfunction similar to that observed in patients with brain stem lesions has been described in acute injuries as well as in chronic whiplash patients.[8,9] In our study 16 whiplash subjects (62%) showed pathologic oculomotor test results in at least one of the smooth pursuit tests and in one of the voluntary saccades tests 2 years after injury. There was a good association between the oculomotor functions and repositioning functions. Smooth pursuit tests correlated with active range of cervical motion. These results suggest that restriction of cervical movements and changes in the quality of proprioceptive information from the cervical spine region affect voluntary eye movements. The same conclusion was proposed by Karlberg and coworkers.[33] Previous studies illustrate the presence of mechanoreceptive and nociceptive nerve endings in cervical facet capsules proving that these tissues are monitored by the central nervous system and implying that neural input from the facets is important to proprioception and pain sensation in the cervical spine.[34] In our study significant correlations occurred between active range of cervical motion and oculomotor performances as well as kinesthetic sensibility, which could indicate that the zygapophysial joints' dysfunction mediates this proprioceptive dysfunction. In the present study, patients with oculomotor and kinesthetic sensibility dysfunction were older than the patients whose test results were normal. No correlations between age and oculomotor and kinesthetic sensibility were observed for the control group. For whiplash subjects age and sex seem to correlate with cervical kinesthetic performances and with

Table 4: Comparison of Repositioning Accuracy Between Subjects With Dysfunction in Smooth Pursuit and Voluntary Saccade (*n* = 16) and Subjects With Normal Oculomotor Function (*n* = 10)

	Oculomotor Test Performances		
	Normal Mean (SD)	Dysfunctional Mean (SD)	*p*
Repositioning accuracy			
Rotation left			
R	2.91 (1.99)	3.73 (2.67)	<.01
X	−.18 (3.08)	.11 (3.99)	NS
Y	−.67 (1.96)	−.67 (2.49)	NS
Rotation right			
R	3.31 (3.23)	4.67 (3.57)	<.001
X	.11 (4.05)	.02 (5.40)	NS
Y	−.50 (2.31)	−.48 (2.73)	NS
Extension			
R	3.72 (3.11)	4.08 (2.76)	NS
X	.07 (1.74)	.04 (2.59)	NS
Y	−.58 (4.61)	−1.08 (4.21)	NS
Flexion			
R	3.63 (3.58)	4.58 (3.96)	<.05
X	.03 (1.62)	.30 (2.36)	NS
Y	.48 (4.89)	1.45 (5.56)	.06

Table 5: Data on Smooth Pursuit and Saccade Movements for Whiplash Subjects 2 Years After Trauma

	Women Mean (SD)	Men Mean (SD)	*p*
Smooth pursuit			
% of Gain 1.0			
20°/sec left	68 (16)	66 (9)	NS
20°/sec right	61 (15)	68 (9)	NS
30°/sec left	63 (25)	69 (16)	NS
30°/sec right	65 (17)	67 (15)	NS
No. of superimposed saccades			
20°/sec left	1.1 (1.1)	0.8 (0.9)	NS
20°/sec right	1.9 (1.6)	0.7 (0.7)	.01
30°/sec left	2.3 (1.4)	1.5 (0.6)	.05
30°/sec right	2.4 (1.2)	1.5 (0.8)	.05
Saccades			
Accuracy, %			
Left	92 (4.8)	91 (2.7)	NS
Right	92 (3.1)	93 (2.7)	NS
Latency, msec			
Left	292 (138)	216 (52)	.05
Right	308 (109)	255 (73)	NS
Velocity, °/sec			
30° Left	354 (38)	396 (48)	.02
30° Right	318 (41)	375 (73)	NS
40° Left	374 (47)	406 (90)	NS
40° Right	380 (50)	413 (80)	NS
50° Left	373 (55)	424 (80)	.05
50° Right	379 (57)	403 (83)	NS

oculomotor functions. This fact could indicate that elderly people and women are more vulnerable to injuries affecting the proprioceptive systems.

A hypothesis presented by Johansson and Sojka[35] proposes the possible mechanisms for genesis/dissemination of muscular tension and for feedback that increases reflex-mediated muscle tension. Increased muscle spindle sensitivity may also be mediated by the sympathetic nervous system acting on the intrafusal fibers of the muscle spindles as a second feedback loop[36]; the interneuron-to-motor neurons connection in the spinal cord may also contribute to increased muscle tension.[37] If increased muscle tension and sensitized muscle spindles are postulated, the increased sensitivity of the muscle spindles may give rise to erroneous proprioceptive signaling, especially if spindles in different neck muscles or on different sides of the neck are unequally sensitized.[38] Erroneous cervical proprioceptive information converges in the central nervous system with vestibular and visual signals, with a consequent feeling of dizziness or unsteadiness caused by a distorted mental representation of body orientation and by a misinterpreted relation to surroundings. In our study, whiplash subjects with complaints of dizziness showed greater repositioning error than subjects without dizziness. Furthermore, whiplash subjects with arm weakness, paresthesia, or pain irradiation to the limb had a larger repositioning error than subjects without radiculopathy declaims. Similar findings have been reported by Persson and coworkers[39] in patients with cervical root compression due to disk hernias or spondylosis but without medullary compression.

CONCLUSION

Some of the patients who claimed no symptoms after trauma showed oculomotor dysfunction and repositioning dysfunction. Neck pain measured with VAS did not correlate significantly with oculomotor performance and kinesthetic sensibility in this study. These results point to a multifactorial background of the chronic morbidity after whiplash trauma. However, a proprioceptive dysfunction might be one of the most important factors for understanding the morbidity after a noncontact whiplash trauma to the neck.

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Supplier

a. SPSS Inc., Suite 330, 444 North Michigan Avenue, Chicago, IL 60611.