ORIGINAL ARTICLE

Comparison of Sensorimotor Disturbance Between Subjects With Persistent Whiplash-Associated Disorder and Subjects With Vestibular Pathology Associated With Acoustic Neuroma

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ABSTRACT. Treleaven J, LowChoy N, Darnell R, Panizza B, Brown-Rothwell D, Jull G. Comparison of sensorimotor disturbance between subjects with persistent whiplash-associated disorder and subjects with vestibular pathology associated with acoustic neuroma. Arch Phys Med Rehabil 2008;89: 522-30.

Objective: To determine if differences exist in reported symptoms and in outcomes of sensorimotor tests (cervical joint position error [JPE], neck-influenced eye movement control, postural stability) between subjects with persistent whiplash and subjects with unilateral vestibular pathology associated with acoustic neuroma.

Design: Repeated measures, case controlled.

Setting: Tertiary institution and metropolitan hospital.

Participants: Twenty subjects with persistent whiplash, 20 subjects with acoustic neuroma, and 20 control subjects.

Interventions: Not applicable.

Main Outcome Measures: Symptom descriptors, Dizziness Handicap Inventory (short form), measures of cervical JPE, the smooth pursuit neck torsion (SPNT) test, and forceplate measures of postural stability in comfortable and narrow stances.

Results: The results showed differences in SPNT (P=.00), selected measures of postural stability (P<.04), and reported symptoms between the whiplash and vestibular groups. There was no between-group difference in cervical JPE (P>.27) or dizziness handicap (P>.69).

Conclusions: This study showed differences in sensorimotor disturbances between subjects with discreet whiplash and those with vestibular pathology associated with acoustic neuroma. The results support the SPNT test as a test of cervical afferent dysfunction. Further research into cervical JPE as a discreet test of cervical afferentation is warranted.

Key Words: Balance; Dizziness; Eye movements; Gait disorders, neurologic; Sensorimotor; Neck; Neuroma; Proprioception; Rehabilitation; Vestibular diseases; Whiplash injuries.

DIZZINESS AND UNSTEADINESS are common symptoms reported by people who present with a discreet but persistent whiplash-associated disorder (WAD) and who have no known vestibular pathology. The characteristics of the dizziness in this group are similar to those reported for dizziness of cervical origin.[1] In association with these symptoms, impairments have been measured in tests of sensorimotor control—namely, cervical joint position error (JPE),[1,2] neck-influenced eye movement control (the smooth pursuit neck torsion [SPNT] test),[3,4] and measures of postural stability using comfortable and narrow stances.[5-10] Impairments in these measures were greater in those subjects reporting dizziness and/or unsteadiness, and no associations were found between the 3 measures and medication intake, compensation status, anxiety, or age.[1,4,10] In our previous studies, only subjects with a discreet local whiplash injury to the cervical area were included. Those with a direct blow to the head, loss of consciousness, or amnesia as a result of the motor vehicle collision were excluded to limit the possibility of a central cause of their symptoms. Although the impairments reported are consistent with a cervical cause, it is possible that either a cervical or vestibular deficit or a combination of these causes may contribute to the presenting symptoms. Further, it is difficult to rule out vestibular dysfunction after a whiplash injury, because our clinical tests do not test the entire system. Thus it would be an advantage to identify whether or not the relatively simple tests of cervical JPE, SPNT test, and postural stability might be useful to determine cervical versus vestibular causes of sensorimotor impairment in WAD. Cervical JPE is currently regarded primarily as a measure of cervical afferent input.[11,12] We would not expect it to be abnormal in subjects with known vestibular pathology without a history of neck dysfunction, but this assumption has not been investigated.[2,13,14] The SPNT test has been shown to differentiate between subjects with neck pain and vestibular pathology and is considered to be a specific test of cervical afferent dysfunction. Tjell and Rosenhall[3] showed that subjects with whiplash had a change in eye movement control when the neck was torsioned—that is, when the trunk was rotated 45° while the head remained stationary. Subjects with vestibular pathology showed no change in eye movement control with this test. The group tested by Tjell and Rosenhall,[3] however, had Meniere's disease, a degenerative condition that can be variable in presentation with periods of exacerbation and remission. A comparative study between subjects with whiplash and those with a discreet loss or ongoing unilateral vestibular pathology, such as acoustic neuroma,[15,16] was considered preferable and thus was selected for our study. We expected that this vestibular group would also show no abnormality in the SPNT test.[3] Although the findings from both laboratory and clinical tests of postural stability may show impaired function in both whiplash and vestibular patients, results from our previous research on subjects with WAD[10,17] suggest that the response patterns from the postural stability

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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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0003-9993/08/8903-11303$34.00/0
doi:10.1016/j.apmr.2007.11.002

test in comfortable and narrow stances may be different between the 2 groups.[18-20]

The aim of this study was to compare physical measures of cervical JPE, the SPNT test, and postural stability in comfortable, narrow, and tandem stances as well as the nature of the reported symptoms between subjects with WAD and subjects who had unilateral vestibular pathology associated with the diagnosis of an acoustic neuroma. It was hypothesized that, compared with whiplash subjects, subjects with unilateral vestibular pathology associated with acoustic neuroma would not show either abnormal cervical JPE or SPNT test results and would present with a different response pattern of postural stability.

METHODS

Participants

Three groups of subjects were sought for this study: those with unilateral vestibular pathology, those with persistent but discreet WAD, and healthy controls of similar age. The unilateral vestibular pathology group was made up of subjects who either had surgery for removal of an acoustic neuroma or had been diagnosed with an acoustic tumor within the past 3 months to 5 years. Potential subjects were recruited from a database of 145 acoustic neuroma patients from a large metropolitan hospital. Exclusion criteria included any reported period of unconsciousness; a neck or head injury; psychiatric disorders; neurologic deficits; hip, knee, or ankle pathology; or neck pain requiring treatment in the past 3 months. Subjects with large tumors that could cause signs and symptoms related to central nervous system dysfunction were not included. The medical charts and any surgical notes were reviewed, and 99 patients were considered unsuitable because of age or documented concomitant pathology. Of the remaining 46 potential subjects, 35 were contactable. Twenty-seven people were willing to participate, but on further questioning 7 were excluded because 4 had a previous history of whiplash injury, 1 had had a neck fracture as a child, 1 had rheumatoid arthritis, and another had a history of a blunt head injury. Thus 20 vestibular subjects (11 men, 9 women) were admitted into the study. The age range of the acoustic neuroma subjects was between 33 and 59 years (mean, 51y). Twelve subjects had had their tumors removed on average 15 months before this study (range, 3−48mo). Eight subjects were being managed conservatively. The mean time since removal of the tumor or diagnosis of the tumor was 23 months (range, 3−60mo).

Twenty subjects within the ages of 40 to 60 years who had sustained a whiplash injury from a motor vehicle collision and who were still symptomatic at least 3 months postinjury, with dizziness or unsteadiness as a primary complaint, were recruited from consecutive eligible patients attending a whiplash research unit at a tertiary educational institution. To ensure that the symptoms could be attributed predominantly to a neck injury, potential subjects were excluded if they reported a period of unconsciousness, posttraumatic amnesia (PTA), or concurrent head injury with the whiplash injury or if they presented with known or suspected vestibular pathology such as benign paroxysmal positional vertigo, a history of dizziness before the whiplash injury, psychiatric conditions, neurologic deficits, and hip, knee, or ankle pathology. Subjects were not considered if they were unable to actively turn the head to 45° to the left or right without increased pain, which would preclude them from performing the SPNT test. Subjects with whiplash accepted into the study all had symptoms that were not abating and were categorized as WAD according to the Quebec Task Force classification.[21] Subjects with whiplash included 15 women and 5 men whose mean age was 46.5 years (range, 40−60y). The mean length of time after injury was 17 months (range, 4−36mo).

A control group of 20 subjects of similar ages to the whiplash and vestibular subjects were drawn from healthy volunteers who responded to advertising in the local media and on campus. To be included in the study, volunteers were to have had no current or past history of whiplash, neck pain, headaches, or dizziness. Fourteen subjects in the control group were women. The mean age of this group was 49.5 years (range, 43−59y).

All participants provided their informed consent. Ethical clearance for this study was granted from both the Hospital Research Ethics Committee and the University Medical Research Ethics Committee, and all procedures were conducted according to the Declaration of Helsinki.

Measurements

Questionnaires. A series of questionnaires were completed to provide a profile of the characteristics of dizziness, measures of anxiety, and perceived disability related to dizziness. A general questionnaire provided information related to the history of the whiplash injury or acoustic neuroma, compensation status, current pain level using a visual analog scale, and current regularly used medications. The Dizziness Handicap Inventory−Short Form (DHI-SF)[22] was used to measure the perceived handicap associated with symptoms of dizziness or unsteadiness. This tool has been shown to be a reliable and valid measure of handicap associated with dizziness.[22] The State Trait Anxiety Inventory−Short Form (STAI-SF)[23] monitored both the “state” (how subjects felt at the time of the investigation) and the “trait” (how they generally felt) and provided a measure of anxiety associated with whiplash. Reliability of this tool has also been established.[23] A dizziness unsteadiness pro forma sought descriptions of symptoms, their duration, and provocative factors.[1] It was completed by the whiplash and acoustic neuroma subject groups.

Cervical JPE testing. For each subject the accuracy in relocating the natural head posture (cervical JPE) was tested after active cervical movements into left and right rotation and extension, using methodology previously described[1] and adapted from Revel et al.[24] The Fastrak[a] was used to measure the difference in degrees between the starting (zero) and the return position for each of the 3 movements tested. One sensor was placed on the spinous process of C7, and the other was attached to a light-weight helmet adjacent to each subject’s forehead. The Fastrak was connected to a personal computer that continually recorded the position of the sensors relative to the source during each test sequence. A software program was written to format and process the data for 3-dimensional analysis of the starting position (zero) and the position to which the head returned. An electronic switch marked the head return position. Data were converted into files and graphs so that the process could be visualized in real time to improve accuracy of testing. Data consisted of a 3×3 matrix of direction cosines for orientation of the forehead sensor relative to the sensor at C7. This was then analyzed to give a 3-dimensional measurement of the position of the head relative to the C7. The difference between the starting (zero) and position on return was calculated in degrees for each of the 3 movements tested. This difference represented the accuracy with which the subjects could relocate the natural head posture, the JPE. The error in the primary plane of movement was used as the measure for JPE, because this had previously been shown to depict differences between healthy controls and subjects with WAD.[1]

SPNT test. Electro-oculography was used to measure and record eye movement while the eyes followed a moving target. The subject's head and trunk were in a neutral forward-looking position initially, and for the second part of the test, the head was held in the neutral position while the trunk was rotated 45° (torsioned) to the left and then to the right. The procedure has been described elsewhere in detail[4] and is similar to that described by Tjell and Rosenhall.[3] The moving target was a laser light, which was driven by a motor to move through a total visual angle of 40°, 20° to the left, and 20° to the right on 10 occasions. Pairs of Ag/AgCl surface electrodes[b] were placed on each subject's skin just lateral to the eyes to record changes in the corneo-retinal potential during eye movement. A ground electrode was placed on the forehead. The signals were passed through a 70Hz low-pass filter and stored on a personal computer.

For each test, the data were graphed using a LabView program.[c] The average velocity of the eye movements was calculated by subtracting the corrective movements from the total excursion of the gaze. A software program was written to calculate the total excursion of each gaze and to allow manual identification and subtraction of the corrective saccades. The program then formulated the corrected gain for each cycle. The top and bottom directional changes of the trace, the square waves,[25] and blinks (judged from recorded examples of an actual blink from each subject) were disregarded from the analysis. The mean gain (ie, the ratio between the eye movements and movement of the target) from the sixth to the ninth cycles was the measure used to define smooth pursuit movements. The smooth pursuit gain was calculated with the neck in a neutral position and also with the neck in a torsioned position. The average gain was calculated for neutral (smooth pursuit neutral) and torsion to the left (smooth pursuit left) and right (smooth pursuit right). The difference between the gain in neutral and the average values in torsion to the left and right is the smooth pursuit neck torsion difference, which is the SPNT test value.

Postural Stability

A computerized, stable force platform (40×60cm) measured force changes over time in both the mediolateral (ML) and anteroposterior (AP) directions for the 6 conditions of the Clinical Test for Sensory Interaction in Balance (CTSIB).[26] Subjects were tested in a standardized comfortable stance position on a firm and then a soft surface with eyes open, eyes closed, and with visual conflict (provided by wearing a lightweight paper dome on the head).[27] The soft surface was a piece of high-density foam rubber (10cm thick) placed on the platform.[10,17] Subjects were also tested in narrow stance with feet together over 4 conditions: firm surface (eyes open and closed) and soft surface (eyes open and closed). Narrow stance was included because it was considered of greater difficulty than comfortable stance but not as difficult as tandem stance, where a number of subjects with whiplash and vestibular disorder could fail the test.[10,17,28,29] In tandem stance, tests of eyes open and eyes closed on a firm surface only were used. For the analysis of postural stability, the sway trace was analyzed by a Wavelet analysis using Daubechies filter 6 for the comfortable and narrow stance tests. The wavelet transform converts the signal data into coefficients that capture the information about the signal at locations within the signal for the different frequencies. The variance of the wavelet coefficients is a measure of the amount of information coming from the different locations and frequencies and is termed "energy." The total of the coefficients from the AP and ML traces at the first 4 frequencies (total energy) was used to summarize the information contained in the trace as directed by our previous research. Higher-frequency components were deemed noise.[10,17]

Procedure

Each subject undertook the 3 sensorimotor control tests. The order was randomized. The starting position for the JPE tests was in sitting with the head in the neutral resting position. Subjects were blindfolded and were asked to perform the test neck movement within comfortable limits, returning as accurately as possible to the starting position. Subjects indicated verbally when they had returned to the starting position and this was marked electronically. The examiner, guided by real-time display, manually repositioned each subject's head back to the original starting position before each trial. Three trials were performed each of left and right neck rotation and then extension. Subjects were able to visually recenter the starting position before each new movement direction.[1] Cervical JPEs were calculated for each direction by using the mean of the absolute errors.[1] Repeatability and reliability of this measure have been established.[30]

For the SPNT test, subjects were instructed to keep the head still and follow the light as closely as possible with their eyes while trying not to blink. To assist with interpretation of the signal, each subject performed 3 blinks (as a recording of blinks for that subject) immediately before the target commenced moving. The test was performed in 3 different starting positions. The first was with the neck in a neutral position—that is, each subject faced straight ahead. For the second test, the head was kept in a neutral position, and each subject's torso was actively turned to an angle of 45°. Once in the desired neck torsion position and after a short pause, the visual stimulus was presented again and the test repeated. The procedure was repeated in the opposite direction of neck torsion. The SPNT test value was calculated as the difference between the neutral and average gain in the torsioned positions.[3]

Subjects stood on the force platform for tests of standing balance. The standardized procedure of the CTSIB was performed with each subject completing the 6 conditions in comfortable stance. The 4 conditions in narrow stance were then conducted. Subjects were asked to place the middle of the right foot to the right of the marked center point of the forceplate; the left foot was placed parallel and as close as possible to the right foot. The 2 tandem stance measures of eyes open and eyes closed on a firm surface were then performed. One 30-second trial was performed for each balance condition. For all tests, an inability to stand without losing balance for a 30-second time period was recorded as failure to complete the particular test.

Data Analysis

The frequencies of responses from dizziness pro forma were collated for comparisons of responses between vestibular and whiplash subjects. Both the state (how subjects felt at the time of the investigation) and the trait (how subjects generally felt) anxiety short scores of the STAI-SF[23] were prorated to the full score to allow comparison with other studies. The scores were calculated out of a possible score of 80, where a score of 20 indicates little anxiety and a score of 80 indicates maximum anxiety. The DHI-SF[22] was scored out of a possible score of 13, where 13 indicates no dizziness handicap and 0, maximum handicap.

The vestibular group was not homogeneous. Thus, preliminary exploratory analyses were performed to determine whether there were any differences for any of the test variables with respect to age (younger group 33−52y vs 55−59y), whether or not the tumor had been removed, the side of lesion, whether or not subjects complained of regular dizziness, and whether or not any neck stiffness or minor neck pain was reported. This analysis showed that within the vestibular group there were no differences in any of the test variables with respect to whether or not the tumor was removed, side of lesion, or reported neck stiffness or pain. There were minimal differences for age and the symptom of dizziness. Significant differences between neck extension JPE (F=4.8, P=.04) and the test of standing balance (visual conflict on the firm surface, medial lateral direction only [F=4.7, P=.04] were observed when subjects were grouped according to the presence of dizziness. Subjects complaining of dizziness had greater deficits in both measures. For age (<52y), only the balance test of narrow stance on the firm surface with eyes open in the AP direction showed a significant effect in the older age group (F=5.14, P=.04). With so few differences seen over all variables, it was considered appropriate for the main analysis to consider the vestibular group as a whole.

An analysis of deviance using the normal distribution was used to investigate any differences between groups for age, trait and state anxiety scores, and the DHI-SF score. Failure rates for each postural stability test were compared between whiplash, vestibular, and control subjects, and the probability of difference of failure rates from controls was calculated for each test using a Fisher exact test. A generalized linear model, repeated-measures analysis of variance using a Bonferroni method, was used to investigate any group differences between the control, vestibular, and whiplash subjects in cervical JPE for extension, rotation to the left and right, the SPNT test, and logged values for AP and ML for each of the comfortable and narrow stance tests. Receiver operating characteristic (ROC) curves[31] were constructed for each of the tests of cervical JPE, the SPNT test, and comfortable and narrow stance balance tests to determine each test's ability to specifically discriminate between whiplash and vestibular subjects. The ROC curve represents the sensitivity versus specificity for every possible cutoff point. The statistical programs R[d] and SPSS[e] were used for all calculations.

RESULTS

The scores for the anxiety and dizziness handicap questionnaire for the acoustic neuroma and whiplash groups are presented in table 1. There were no differences for age, anxiety scores (state, trait), or DHI-SF scores between the acoustic neuroma and whiplash groups. Table 2 presents a comparison of the frequency of use of descriptors and aggravating and associated features of the dizziness or unsteadiness between the whiplash and acoustic neuroma group. As can be observed, there was some commonality between groups in descriptors chosen, average intensity, frequency, and duration of dizziness or unsteadiness. However, in the whiplash group headache, neck positions, or moving quickly were reported most frequently to aggravate symptoms, and concurrent symptoms of headache, nausea, blurred vision, and sweating were most often reported. In the acoustic neuroma group, common exacerbating features were walking in busy or crowded places, moving quickly (conditions that challenge gaze stability), or stress; concurrent symptoms were most often ringing in the ears, blurred vision, hearing loss, and confusion (see table 2).

Table 1: Questionnaire Scores for the Whiplash and Vestibular Groups

Questionnaire	Whiplash	Vestibular	F (*P*)
State anxiety (/80)	33.1±2.8	30.5±1.6	0.32 (.73)
Trait anxiety (/80)	44.4±3.6	37.1±2.4	1.37 (.27)
DHI score/13	7.6±.69	8.5±.78	0.36 (.69)

NOTE. Values are mean ± standard error of the mean.

Table 2: Comparison of the Frequencies of Dizziness Symptom Descriptions, Exacerbating Features, and Concurrent Symptoms in Whiplash (n=20) and Vestibular (n=20) Subjects

Descriptions, Features, and Symptoms	Vestibular (%)	Whiplash (%)
Description		
Lightheaded	35	70
Unsteady	80 (falling/veering, off balance)	65 (might fall, imbalance)
Visual disturbances	40 (must focus when walk)	60 (eyes jiggle, must focus)
Giddy	40 (giddy, room spinning)	30 (giddy, dizzy)
Other	50 (drunkenness, fogginess)	55 (sea legs, fogginess)
Exacerbating features		
Walking busy/crowded places	45	10
Moving quickly	35	30
Stress	35	0
Loud noises	25	0
Headache	20	45
Moving neck quickly	20	15
Certain neck positions	5	30
Neck movements	5	20
Associated features		
Ringing in ears	35	10
Blurred vision	25	35
Hearing loss	15	0
Decreased concentration	15	20
Headache	0	50
Nausea	10	35
Sweating	10	30
Frequency		
Daily or several times a week	70	84
Intensity	32	47
Duration		
Few seconds to few minutes	50	70

Postural Stability

Comfortable stance. The mean and standard errors for the logged energy values for each test in comfortable stance for the whiplash, vestibular, and control groups for the AP and ML directions are depicted in figures 1A and 1B. The results indicated that across all comfortable stance conditions, there was a trend for the total energy of the sway to be greater in the whiplash group than the acoustic neuroma group. However, only tests of eyes open AP (P=.02) and visual conflict ML (P=.04) on the soft surface showed significantly greater energy of sway.

Subjects with whiplash had significantly greater sway over all tests compared with controls (P<.01), whereas subjects with acoustic neuroma had significantly greater sway when compared with controls only on the eyes open AP (P=.01) and closed ML (P=.01) tests on the firm surface.

Narrow stance. The narrow stance condition of eyes closed on the soft surface in the ML direction showed a

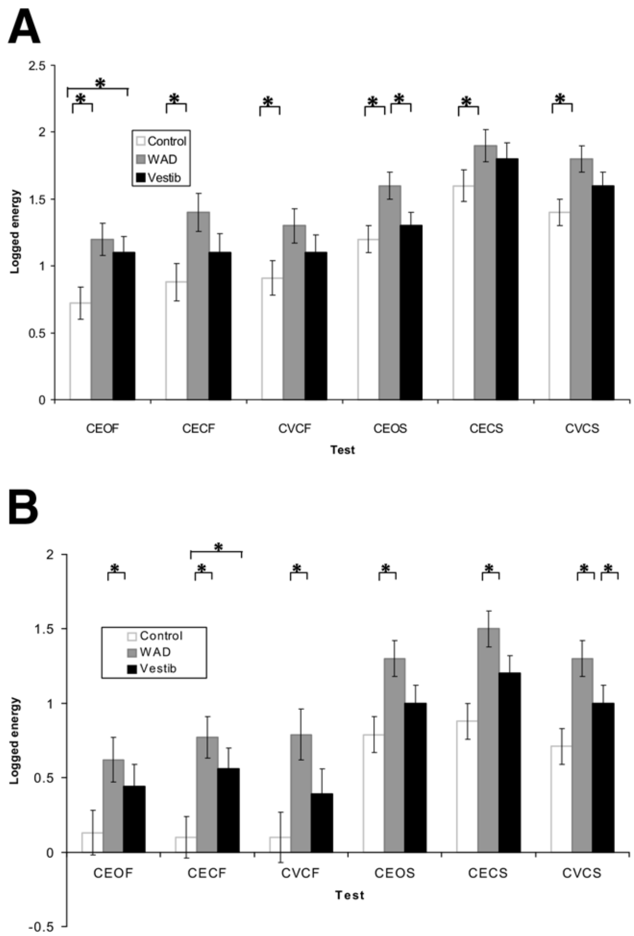

Fig 1. (A) Comparison of mean and standard error (SE) of total energy for each comfortable stance test (AP direction) between controls, whiplash, and vestibular (vestib) groups. (B) Comparison of mean and SE of total energy for each comfortable stance test (ML direction) between controls, whiplash, and vestibular groups. Abbreviations: C, comfortable stance; ECF, eyes closed firm; ECS, eyes closed soft; EOF, eyes open firm; EOS, eyes open soft; VCS, visual conflict soft; VCF, visual conflict firm. *$P<.05$.

significant difference between subjects with whiplash and acoustic neuroma, with the greater deficits noted in subjects with acoustic neuroma ($P=.001$) (figs 2A, 2B). Furthermore, subjects with acoustic neuroma (25%) more often lost stability on the soft surface with the eyes closed compared with subjects with whiplash (10%) and the control group (0%) (table 3). All subjects successfully completed the other comfortable and narrow stance tests.

Subjects with whiplash had significantly greater sway in both the AP and ML directions for eyes closed, firm surface in narrow stance compared with control subjects ($P<.02$) and for the AP direction for eyes open and closed on the soft surface ($P<.03$). In contrast, subjects with acoustic neuroma had significantly greater sway in the ML direction for eyes closed firm and eyes open soft conditions and both AP and ML for eyes closed soft surface when compared with control subjects ($P<.01$).

Tandem stance. In tandem stance, there was no difference between subjects with whiplash and acoustic neuroma, with both groups losing stability significantly more often than controls, particularly in tests with altered vision (see table 3).

Cervical JPE

There were no significant differences between subjects with acoustic neuroma and whiplash for cervical JPEs in any direction. Both groups had significantly greater errors in extension and rotation to the right when compared with control subjects (fig 3).

SPNT Test

Subjects with whiplash had significantly higher SPNT test scores than both control and subjects with acoustic neuroma ($P<.01$) (fig 4). There was no significant difference between subjects with acoustic neuroma and control subjects ($P=1.00$).

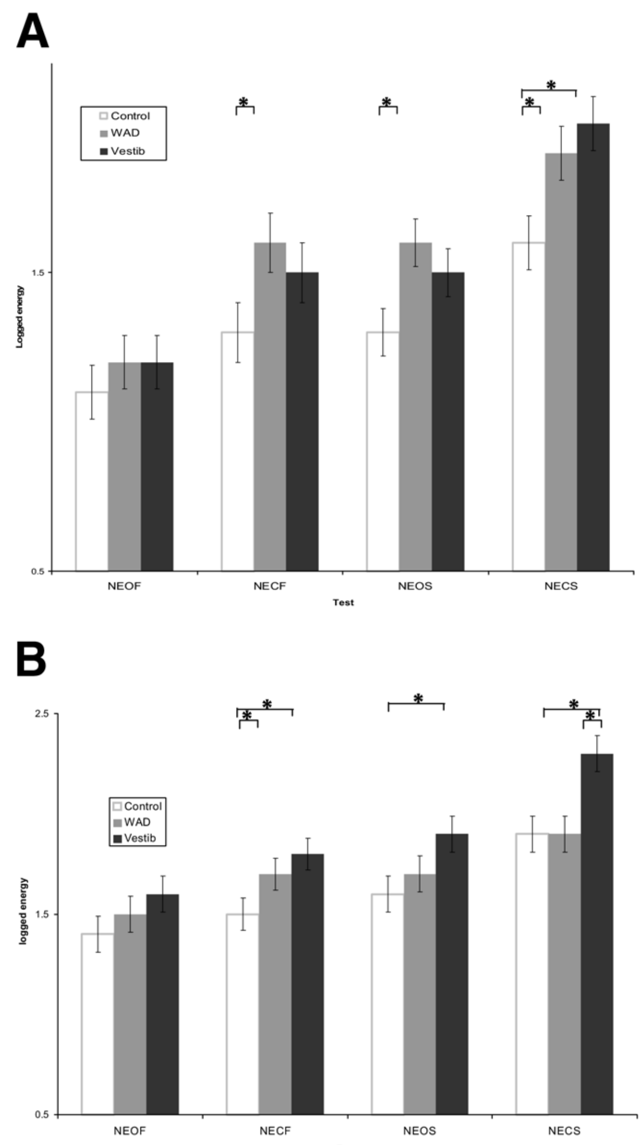

Fig 2. (A) Comparison of mean and SE of total energy for each narrow stance test (AP direction) between controls, whiplash, and vestibular groups. (B) Comparison of mean and SE of total energy for each narrow stance test (ML direction) between controls, whiplash, and vestibular groups. Abbreviations: ECF, eyes closed firm; ECS, eyes closed soft; EOF, eyes open firm; EOS, eyes open soft; N, narrow stance. *$P<.05$.

Table 3: The Percentage of Control, Whiplash, and Vestibular Subjects Unable to Complete Balance Tests and the Statistical Significance of Group Difference Compared With Subjects in Failure Rates

Balance Test	Control (%)	Whiplash (%)	Vestibular (%)	Whiplash (*P*)	Vestibular (*P*)
Narrow eyes closed soft	0	10	25	.487	.047
Tandem eyes open	0	60	45	.000	.001
Tandem eyes closed	30	90	95	.000	.000

Discriminating Between Subjects With Whiplash and Acoustic Neuroma

Table 4 presents the results for the area under the ROC curves for each of the tests of cervical JPE, the SPNT test, and comfortable and narrow stance postural stability tests, showing their ability to discriminate between subjects with whiplash and acoustic neuroma. The ROC curves identified that the SPNT test as well as some of the postural stability conditions were able to discriminate between the 2 groups. The postural stability conditions were as follows: comfortable stance tests with the eyes open on the soft surface for the AP and ML directions, comfortable stance with visual conflict on the soft surface in the ML direction, and narrow stance with eyes closed on the soft surface in the ML direction. In the comfortable stance tests, greater energy of sway determined a subject with whiplash whereas in the narrow stance test, greater energy indicated a subject with an acoustic neuroma.

DISCUSSION

The results in this cohort of subjects indicated that, in tests of the SPNT test and selected surface, stance, and visual conditions of standing balance there were significant differences between subjects with persistent WAD complaining of dizziness and/or unsteadiness when compared with subjects with unilateral vestibular pathology associated with an acoustic neuroma. There were no differences in the tests of cervical JPE between these 2 groups.

In the SPNT test, subjects with whiplash showed a decrease in eye movement control when the neck was in a relatively torsioned position in contrast to the lack of change in vestibular or control subjects. Similar findings were observed in an earlier study by Tjell and Rosenhall.[3] Both studies provide evidence to strengthen the proposal that the SPNT test is a test of cervical afferent dysfunction.

Some differences were also shown between the whiplash and acoustic neuroma subjects when postural stability was tested. Subjects with whiplash showed greater deficits in selected comfortable stance tests, whereas subjects with acoustic neuroma had a greater deficit and more often failed the most challenging narrow stance condition (soft surface, eyes closed). When compared with control subjects, subjects with whiplash had greater sway in all comfortable stance tests and most narrow stance tests in the AP direction. It is considered that the altered cervical afferent input from the whiplash injury could be responsible for this instability. In contrast, subjects with vestibular pathology associated with acoustic neuroma were more unstable than controls in only 2 comfortable stance tests but most narrow stance tests in the ML direction. This suggests that when a comfortable stance position is used, subjects with vestibular pathology generally remain as stable as the age-matched controls but that in narrow stance the vestibular group is more challenged than the whiplash group. The further challenge of tandem stance, however, was equally difficult for both subjects with acoustic neuroma and whiplash compared with control subjects.

The differing results from the postural stability tests may indicate that the causes of the postural stability disturbances are different in subjects with whiplash and acoustic neuroma. Those with whiplash had disturbances in the majority of tests irrespective of the stance or test condition and particularly in the AP direction. This may suggest somatosensory impairment as the cause of the disturbances.[16,26] In contrast, postural stability deficits in subjects with acoustic neuroma, who may have compensated for their dysfunction using other available senses (because at least 3 months had elapsed since surgery or diag-

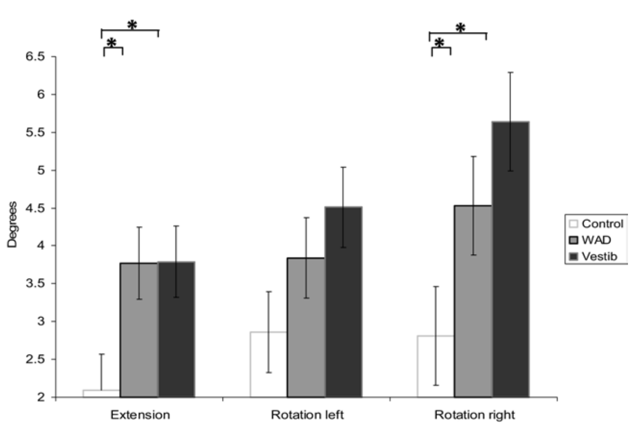

Fig 3. Comparison of mean and SE of cervical JPE between controls, whiplash, and vestibular groups. **P*<.05.

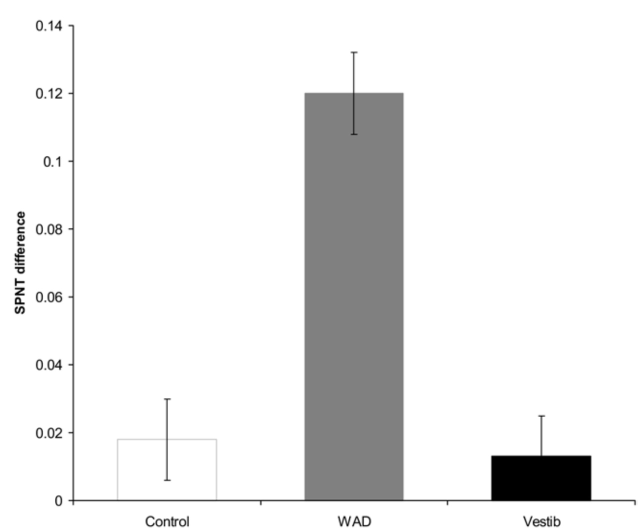

Fig 4. Comparison of mean and SE of SPNT test difference between controls, whiplash, and vestibular groups.

Table 4: ROC and Area Under the Curve, Showing the Discriminating Ability of Each Test Between Subjects With Whiplash and Vestibular Subjects

Variable	Area	Standard Error	*P*
Cervical JPE			
Extension	.53	.09	.77
Left rotation	.45	.09	.59
Right rotation	.40	.09	.27
SPNT	.98	.02	**.00**
Balance			
Comfortable stance			
Eyes open firm			
AP	.56	.09	.48
ML	.53	.09	.74
Eyes closed firm			
AP	.64	.09	.14
ML	.62	.09	.18
Visual conflict firm			
AP	.68	.09	**.04**
ML	.54	.09	.65
Eyes open soft			
AP	.68	.09	**.05**
ML	.70	.08	**.03**
Eyes closed soft			
AP	.68	.08	.05
ML	.64	.09	.12
Visual conflict soft			
AP	.68	.08	**.05**
ML	.64	.09	.12
Narrow stance			
Eyes open firm			
AP	.36	.09	.13
ML	.48	.10	.81
Eyes closed firm			
AP	.42	.09	.42
ML	.51	.10	.93
Eyes open soft			
AP	.30	.08	**.03**
ML	.54	.09	.65
Eyes closed soft			
AP	.18	.07	**.00**
ML	.26	.08	**.01**

NOTE. Boldface denotes $P<.05$.

nosis of the tumor) were more evident in more challenging stance and visual conditions particularly in the ML direction, consistent with patterns expected for chronic vestibular dysfunction.[32,33] Levels of anxiety between groups were similar, suggesting that anxiety is an unlikely contributing factor to differences in postural stability between groups. This was also found in previous research of subjects with whiplash.[10]

An unexpected finding was the lack of differentiation between whiplash and acoustic neuroma subjects in all 3 tests of cervical JPE, although both groups had greater errors than control subjects. Possible reasons for these findings include an inadequate sample size, concomitant neck involvement in subjects with acoustic neuromas, or concomitant vestibular involvement in subjects with whiplash (see Study Limitations below). It could also indicate that the cervical JPE test is not a unique test of cervical afferent function.

The results of this study could suggest that the JPE test may be useful in determining sensorimotor control abnormalities due to mismatched afferent input from one of either abnormal vestibular and/or cervical origins but that it may not be useful to differentiate between a vestibular and cervical cause of the disturbances. This implies that the tests may not be specific tests of cervical afferent function as previously thought.[2,13,14] Thus, the mechanisms associated with measurement of cervical JPE need further exploration. Specifically, it needs to be determined whether modification of the test could assist with differentiating a cervical versus a vestibular component. It is thought that coordinated cervical and vestibular input is important to allow the brainstem to estimate the position of the head in space.[34] A change in the sensitivity of the cervicocollic reflex after reduction of the vestibulocollic reflex gain in those with unilateral vestibular pathology could be implicated in the cause of altered cervical joint position sense in vestibular subjects.[35] Nevertheless, the results of recent studies[36-38] investigating a similar test, the subjective straight ahead test, in which subjects are asked to position a laser light in the straight ahead position in a darkened room, showed that changes to both cervical and vestibular input influence the outcome of the subjective straight ahead test. Thus, it is feasible that cervical and vestibular input might also influence cervical joint position sense. Yacovino and Hain[39] recently investigated the effect of added neck muscle vibration on outcomes of the subjective straight ahead test. They found that the accuracy of the subjective straight ahead test decreased in subjects with vestibular pathology compared with control subjects when cervical neck vibration was administered and concluded that added neck muscle vibration increased the sensitivity of the test to show vestibular pathology. In a similar way, further research is necessary to investigate whether cervical versus vestibular dysfunction could be differentiated with manipulation of inputs during tests of cervical JPE.

It may also be important to consider other measures of cervical kinesthetic sense rather than just cervical JPE or position sense.[40] For example, Kristjansson et al[40] recently reported on a new protocol for measuring accuracy of reproduction of a neck movement task. This test was able to effectively discriminate between control and whiplash subjects. It will be important in future studies to determine the ability of the test to discriminate between abnormal vestibular and cervical input. Although the findings of our study have required this discussion, it does not mean that cervical JPE is not a useful measure in subjects with whiplash. The test is often positive in whiplash subjects,[1,2,40-42] and improvements in cervical JPE have been shown with interventions directed primarily to the cervical spine,[39,43,44] but it is possible that it may not be a test exclusive to neck disorders. Further research is necessary to validate these findings in other whiplash and vestibular populations.

It is proposed that when the symptom characteristics and results of all tests are viewed collectively, there is some evidence to suggest that as a set, these tests may assist differentiation between whiplash and vestibular subjects. The whiplash group had positive results in the SPNT test and had greater postural stability disturbances in selected comfortable stance tests. These subjects also reported concomitant and exacerbating symptoms such as increased headache, certain neck positions, or when moving quickly and had associated symptoms of nausea, blurred vision, and sweating, similar to findings in other whiplash cohorts.[1] In contrast, the acoustic neuroma subjects had negative results in the SPNT test, had greater postural stability disturbances in the eyes closed soft surface narrow stance condition, and more often nominated exacerbating features such as walking in busy or crowded places, moving quickly, or when stressed and had associated symptoms such as ringing in the ears, blurred vision, hearing loss, and confusion. It is notable that the description, intensity, and handicap associated with the dizziness (DHI-SF) were similar between these subject groups.

Study Limitations

It is acknowledged that subject numbers were relatively small in this study, because of difficulty in recruiting subjects with acoustic neuroma. Nevertheless, subsequent power analysis for both selected postural stability tests and the SPNT test between controls and subjects with whiplash indicated that this difference was found with a greater than 90% certainty. In contrast, power for cervical JPE tests was poor (<0.5), although if the cervical JPE results were due to poor power, trends toward greater differences in subjects with whiplash compared with acoustic neuroma subjects would have been expected (see fig 3). It could also be argued that acoustic neuroma subjects, particularly those who have had surgery, might have concomitant neck involvement, particularly if there was any surgical interruption or secondary effect on muscles such as the sternocleidomastoid or trapezius muscles. However, there was no difference between subjects with acoustic neuroma who complained of any neck symptoms or between subjects with or without surgery on any of the JPE measures. On the other hand, it is also possible that subjects with whiplash might have some undiagnosed vestibular pathology, which potentially could confound our findings. We did not screen for this. Subjects with whiplash in this study were excluded if they reported a period of unconsciousness, PTA, or concurrent head injury with the whiplash injury or if they presented with known or suspected vestibular pathology such as benign paroxysmal positional vertigo. These exclusions would limit the likelihood of people being entered into the study with vestibular involvement; however, this screening would not completely rule out potential vestibular dysfunction after a whiplash injury in all participants.

CONCLUSIONS

The results of this study suggest that the relatively simple and non–pain provocative test of SPNT might be useful to distinguish between cervical afferent and vestibular dysfunction in subjects with whiplash. These findings would be augmented by tests of postural stability and descriptions of symptoms. Tests of cervical JPE showed sensorimotor control abnormalities but were not different between subjects with whiplash and acoustic neuroma. This finding could imply that tests of cervical JPE are not unique tests of cervical afferent. Further research is required to investigate the mechanisms associated with measuring cervical JPE.

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