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Dizziness, Unsteadiness, Visual Disturbances, and Sensorimotor Control in Traumatic Neck Pain



Symptoms such as dizziness, unsteadiness, and visual disturbances and signs of altered head and eye movement control and postural stability are common in those following neck trauma, especially in those with persistent pain.¹¹⁵ Understanding these signs and symptoms and potential origins is important for assessment and relevant rehabilitation. Suggested causes include altered sensorimotor control, vertebral artery dissection or insufficiency, psychosocial factors such as anxiety and

fear avoidance, and medication use.^{34,107,113} Among these factors, research to date indicates that the primary cause is most likely altered sensorimotor control.¹¹⁴

The sensorimotor control system comprises input from the visual, vestibular, and proprioceptive systems, particularly the richly innervated cervical spine, which is integrated in the central nervous

system (CNS) to provide appropriate motor output to control head and eye movement and postural stability.⁵ Potential damage or impairment to components of the sensorimotor control system (cervical spine, vestibular system, or CNS) is possible following traumatic incidents such as a whiplash injury. However, based on animal and human models, in

incidents of relatively low force (ie, low speed and no concussion, loss of consciousness, or a direct blow to the head), sensorimotor control disturbances due to CNS or peripheral vestibular system injury are less likely,^{43,104,107} in contrast to the more likely damage and subsequent functional impairment of the abundant cervical joint and muscle structures and related receptors.^{51,111,129} These cervical receptors provide important input and have unique central and reflex connections to the vestibular, visual, and sensorimotor control systems (FIGURE 1).^{18,82}

After traumatic neck injury, disturbances in sensorimotor control, primarily via altered cervical input, may occur due to a combination of factors. Apart from direct trauma, factors associated with the trauma, such as inflammation,¹¹⁰ functional impairment,³² morphological changes to musculature,²⁹ pain,⁶⁶ and psychological distress,⁷⁹ may alter cervical input or CNS representation. This can influence cervical reflex connections to the visual and vestibular systems and result in subsequent secondary disturbances.⁹⁷ Immediate sustained change in cervical input to the sensorimotor control system following neck trauma may be a more common cause of dizziness, visual disturbances, and unsteadiness, as well as changes in cervical proprioception, head and eye movement control, and postural stability, although other causes of senso-

● **SYNOPSIS:** There is considerable evidence to support the importance of cervical afferent dysfunction in the development of dizziness, unsteadiness, visual disturbances, altered balance, and altered eye and head movement control following neck trauma, especially in those with persistent symptoms. However, there are other possible causes for these symptoms, and secondary adaptive changes should also be considered in differential diagnosis. Understanding the nature of these symptoms and differential diagnosis of their potential origin is important for rehabilitation. In addition to symptoms, the evaluation of potential impairments (altered cervical joint position and movement sense, static and dynamic balance, and ocular mobility and coordination) should become an essential part of the routine

assessment of those with traumatic neck pain, including those with concomitant injuries such as concussion and vestibular or visual pathology or deficits. Once adequately assessed, appropriate tailored management should be implemented. Research to further assist differential diagnosis and to understand the most important contributing factors associated with abnormal cervical afferent input and subsequent disturbances to the sensorimotor control system, as well as the most efficacious management of such symptoms and impairments, is important for the future. *J Orthop Sports Phys Ther* 2017;47(7):492-502. doi:10.2519/jospt.2017.052

● **KEY WORDS:** cervical spine, proprioception, WAD, whiplash

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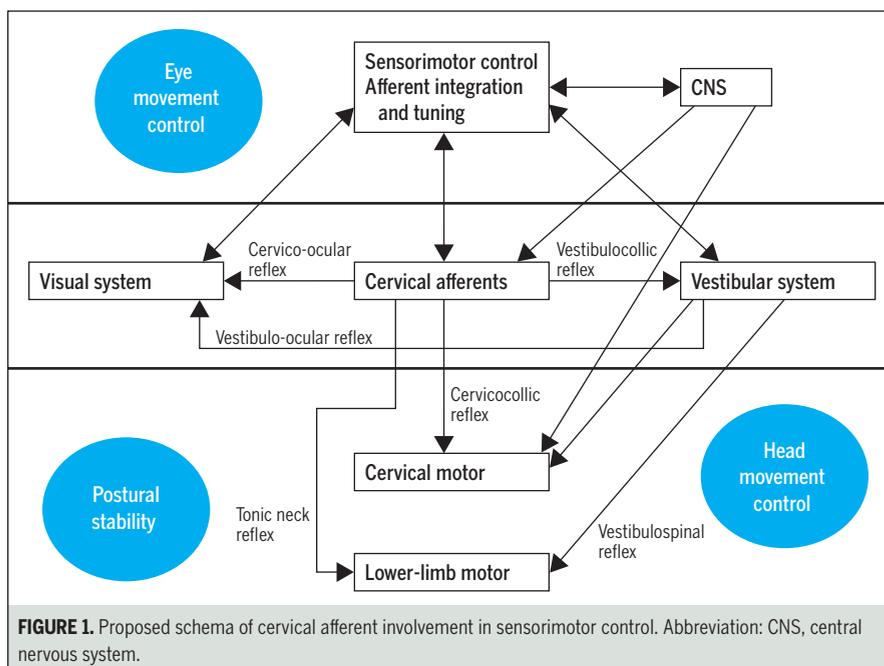


FIGURE 1. Proposed schema of cervical afferent involvement in sensorimotor control. Abbreviation: CNS, central nervous system.



FIGURE 2. Cervical joint position error in neck torsion. A laser is placed on the sternum and projected onto a target 90 cm away. The head is gently held still by the examiner while the individual actively rotates the trunk as far as comfortable and then returns to the starting position as accurately as possible with vision occluded. The difference in degrees between the starting and ending positions is the joint position error.

rimotor control disturbances should also be considered in the differential diagnosis process. The present commentary will explore current evidence for symptoms and signs, clinical assessment, differential diagnosis, and management of sensorimotor control disturbances associated with traumatic neck pain.

EVIDENCE OF SENSORIMOTOR DISTURBANCE

Symptoms

SYMPTOMS CHARACTERISTIC OF CERVICOGENIC dizziness and unsteadiness are often present in patients following neck trauma, especially in those with persistent pain.^{114,121} True vertigo or spinning, typically attributed to vestibular dysfunction, is rarely described, and generally the dizziness is described as vague unsteadiness or light-headedness.¹²¹ Further, exacerbating factors are generally related to increased neck pain, headache, or neck-related movement and activity.^{114,121} Such symptoms have also been associated with reports of loss of balance and falls in some individuals.¹²¹

Symptoms relating to the visual system, such as needing to concentrate to

read, visual fatigue, difficulty judging distances, and light sensitivity, are frequently reported in whiplash-associated disorder (WAD) and idiopathic neck pain (INP) without trauma.¹²⁴ Interestingly, these are symptoms similar to those experienced by some individuals with postconcussion syndrome, additional visual symptoms, such as losing the location on the page and ineffective reading speed, are also often reported.^{61,98} Also, true double vision, which is common in individuals with vertebrobasilar insufficiency, is not commonly reported in traumatic neck pain.¹²⁴

Interestingly, other symptoms often associated with postconcussion syndrome,⁶¹ such as headache, poor concentration,¹⁰⁵ and fatigue,¹⁰⁶ are also common in those with traumatic neck pain. It is possible that this is due to concomitant head trauma associated with neck trauma or vice versa, where potential neck trauma is associated with head trauma.^{30,62,69}

Cervical Proprioception

Joint Position Sense Joint position sense (JPS) is defined as the ability to relocate the natural head position without the as-

sistance of vision.⁸⁸ Greater errors have been shown in individuals with both INP and persistent WAD, although errors are greater in those with neck trauma,²⁴ especially in those with moderate to severe pain and disability.¹⁰⁰ Further, Treleven et al¹²¹ found that individuals with persistent WAD and symptoms of dizziness had greater errors than those not complaining of dizziness, suggesting that these symptoms may be due to greater abnormal cervical afferent input. However, while JPS testing is thought to be a measure of cervical proprioception, deficits have also been seen in those with vestibular pathology in some¹¹⁴ but not other studies.⁶⁷ More recently, to better control for vestibular function, an alternative test of trunk relocation on a stable head has been developed (**FIGURE 2**). Although the test has promise to assist with differential diagnosis, additional research is required before it can be advocated for clinical and research use.¹² Interestingly, position sense deficits have not been isolated to the neck in this population, with deficits also seen in the shoulder and elbow in some patients with traumatic neck pain.^{57,91}

Cervical Movement Accuracy Several studies have looked at accuracy of fine motion control in the neck of those with traumatic neck pain as another measure of proprioception. Kristjansson et al⁵⁹ and Kristjansson and Oddsdottir⁶⁰

demonstrated less accuracy in tracing a computer-generated movement pattern with the head in those with traumatic neck pain when compared to both a control group and individuals with INP. These authors also found that these impairments did not specifically relate to other signs and symptoms associated with WAD and seem to either develop over time or persist.⁷⁶ Woodhouse et al,¹³² using a stationary movement pattern, also demonstrated decreased accuracy in individuals with WAD compared to a control group and individuals with INP. Recently, accuracy in following a moving target in a virtual environment has been shown to be somewhat sensitive and specific to those with neck pain.⁴ To date, no specific differences in those with traumatic neck pain compared to INP have been noted, but this is a continued area of investigation (FIGURE 3).⁴

Vertical Alignment Perception Disturbances in the ability of individuals with neck pain to correctly identify true vertical using the rod and frame test are thought to be suggestive of disturbed cervical proprioception.³ It has been suggested that those with traumatic neck pain may have greater deficits. But, a recent study demonstrated altered vertical perception in those with INP but not WAD.¹²⁵ It was suggested that this might have been due to the complexity of the

measure; therefore, as is, vertical alignment perception may not be a suitable measure of cervical proprioception in those with traumatic neck pain.¹²⁵

Standing Balance

Static Balance Several studies have demonstrated disturbed postural stability in individuals with traumatic neck pain,^{8,68,95,96} especially in those with symptoms of dizziness.¹²⁰ Balance disturbances have also been related to neck muscle fatigue in those with WAD.⁹⁹ Deficits are noted in most testing conditions, including when standing in comfortable, narrow, and tandem stances, and especially when vision is occluded. Sway is usually increased in the anterior-posterior direction, indicative of somatosensory impairment,⁹⁴ although in more difficult tests, a stiffening strategy and less sway, compared to those with INP, has been observed.⁹⁶ These static balance disturbances are likely primarily due to cervical afferent dysfunction rather than vestibular function, as they differ in those with unilateral vestibular pathology.¹²² In addition, individuals with WAD, in a test specifically designed to isolate the cervical afferents, had increased sway with the neck in a torsioned (trunk turned, head still), rather than in a head-rotated, position when compared to a neutral head position.¹³³ These alterations were not seen in either asymptomatic individuals or those with vestibular pathology.^{127,133} This suggests that this test may be specific for those with cervical-related balance deficits.

Dynamic and Functional Balance Dynamic and functional balance can also be affected. Impairments in the step test, timed 10-m walk with and without head turns, tandem walk, and stair walking, as well as delayed corrective responses to destabilizing perturbations while sitting and stepping in place, have been demonstrated in those with persistent WAD.^{13,19,101} Interestingly, similar patterns of balance impairment were present in individuals with traumatic neck pain with and without concussion, but those with concussion had greater balance defi-

cits for stance and complex rather than simple gait tasks.³⁶ This may suggest a combined cervical/vestibular deficit in this population.

Eye Movement Control

Several alterations in oculomotor control, including disturbed eye follow, gaze stability, eye-head coordination, vergence, saccades, and ocular reflex activity, have been associated with traumatic neck pain. Such abnormalities can be present in disorders of the vestibular system, disorders of the CNS, and as a result of abnormal afferent input from the cervical spine.^{47,73,119}

Smooth-Pursuit Neck Torsion

Similarly to balance tests, neck torsion has been used to demonstrate a cervical afferent cause in some tests. Accordingly, abnormalities in eye follow or smooth pursuit when tested in the neck torsion position, compared to a neutral neck position, have been seen in those with WAD but not in those with central or peripheral vestibular pathology.^{111,122} These abnormalities were also greater in those with whiplash who also had symptoms of dizziness.¹¹⁹ In other studies, close associations were noted between performance on the smooth-pursuit neck torsion (SPNT) test and disturbance of reading, driving, and cognitive tasks.⁴¹ This suggests that some common symptoms of posttraumatic neck injury might manifest from disturbed sensorimotor control due to abnormal cervical afferent input. However, others using a fully automated analysis of SPNT^{26,54,58} have not found deficits to the same extent. This may reflect the importance of trained observers to determine and extract the appropriate elements of the signal for analysis. A test to address this problem may be the cervical torsion test. Recently, it has been suggested that nystagmus of greater than 2°/s during sustained neck torsion positions may be an alternative and more sensitive method than SPNT to demonstrate these abnormalities.⁶⁷ However, this was done in individuals with cervicogenic diz-

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FIGURE 3. Cervical movement accuracy. The individual follows a moving target at 10°/s in flexion, extension, and rotation to the left and right while immersed in a virtual reality environment. Sensors in the head-mounted display measure the difference between the target and the individual's head position to give a measurement of accuracy.

ziness and not specifically in those with traumatic neck pain.

While abnormalities in smooth pursuit with the neck in torsion have been linked with cervical afferent disturbances, it is possible that smooth-pursuit abnormalities in the neutral neck position or altered saccadic eye movement may reflect CNS impairment,¹³⁰ which can occur in isolated severe cases of persistent pain following neck trauma.¹²⁹ Further, medications and some psychological conditions can influence eye movement control, although this should not be influenced by neck positions such as neck torsion.³⁹

Gaze Stability Decreased range of head movement while attempting gaze fixation, measured by head and eye movement sensors, has also been seen in those with traumatic neck pain.^{44,117} Recently, physical therapists' ratings of visually assessed head and eye movement control tests, such as gaze stability, were shown to be reliable and also demonstrated impairments in those with neck pain, which included traumatic neck pain,²² enabling clinical application of these measures. However, unlike SPNT, there is not yet a specific test to isolate a cervical afferent cause of gaze stability disturbances.

Ambient Visual System Damage to the ambient visual system, important for spatial orientation, has also been suggested as a possibility following a whiplash injury.⁷⁸ Convergence and accommodation insufficiency and eye alignment malfunctions have been demonstrated in some following a whiplash injury.^{11,102} Together, these symptoms can be labeled as post-trauma visual syndrome.⁷⁸ Nevertheless, research into this area is in its infancy. In those with concussion, more work has been done, and oculomotor deficits, thought to be related to cortical or sub-cortical function, have been shown to be common, especially early postinjury,^{80,128} and may be a persistent feature in some.⁴⁸

Cervico-ocular Reflex An increased gain of the cervico-ocular reflex has also been demonstrated in individuals with whiplash⁷⁰ and recently in those with INP,²³ supporting the theory of cervical afferent

disturbance as the cause of the deficits. Interestingly, when this is seen in people with vestibular pathology and in the elderly, it is thought to be a compensation for a decrease in vestibulo-ocular reflex gain.⁷¹ However, this compensatory response has not been seen in individuals with WAD and may be an important cause of disturbances to the visual system.⁷¹ Further, there is some evidence that reflexive neck muscle activity seen during eye movements, likely mediated by this reflex, is altered in those with WAD.⁷

Eye-Head-Body Coordination

Decreased head velocity during tasks involving head-eye coordination, compensatory head movements during isolated eye rotation,¹¹⁷ reduced precision in an eye-head-hand coordination task,⁹² and impairment in trunk-head coordination (ie, moving the head and trunk independently) have been identified in those with traumatic neck pain.¹²⁶

Sensorimotor Incongruence

Sensorimotor integration has been suggested to be affected in those with traumatic neck pain as a result of impaired cervical proprioception and has been assessed via altered perception of distorted visual feedback or laterality judgment tasks. During a distorted arm coordination task, sensorimotor incongruence was seen in those with both acute and chronic traumatic neck pain.^{20,21} However, a study using laterality judgment tasks did not show impairments,⁸¹ and another, in fact, found improved reaction times and similar accuracy to controls in those with traumatic neck pain.⁹⁰ The authors of the later study suggest that strategies to compensate for altered proprioception may have led to this finding.

PREDICTORS OF POOR RECOVERY

THERE IS SOME EVIDENCE THAT symptoms such as dizziness and signs of sensorimotor control disturbances may be indicative of poorer

prognosis in those with traumatic neck pain.^{15,50,77,83,100} Thus, appropriate assessment, differential diagnosis, and management of clinical features may be important, especially when trying to prevent transition to chronicity.¹¹³

CLINICAL ASSESSMENT

GIVEN THE CURRENT EVIDENCE, EARLY assessment of cervical joint position and movement sense, balance, and oculomotor and coordination disturbances^{55,115} should be routine in all patients with traumatic neck pain, not just in those complaining of symptoms. There is evidence that these features occur soon after injury and are not a response to ongoing pain and disability.^{14,51,100} While there is abundant evidence that these signs and symptoms are most likely due to altered cervical afferent input to the sensorimotor control system, in some individuals, there is potential for other causes, and thus differential diagnosis is important to direct appropriate management. Other considerations are the potential for primary cervical afferent disturbances leading to secondary vestibular impairments,^{37,97} primary vestibular or visual impairments influencing the cervical spine,^{2,89,131} and the presence of concomitant cervical, visual, vestibular, and or mild brain deficits such as those seen following concussion.^{30,69}

DIFFERENTIAL DIAGNOSIS

IT CAN BE DIFFICULT TO PRECISELY determine the causes of sensorimotor control disturbances in those with traumatic neck pain due to potential concomitant deficits (visual or vestibular), as well as secondary adaptations within the sensorimotor control system. Further, certain medications and factors such as anxiety can perpetuate or cause disturbances via several suggested mechanisms.^{39,79}

It is important to consider that even in low-force situations generated during traumatic neck injury, there is potential

[CLINICAL COMMENTARY]

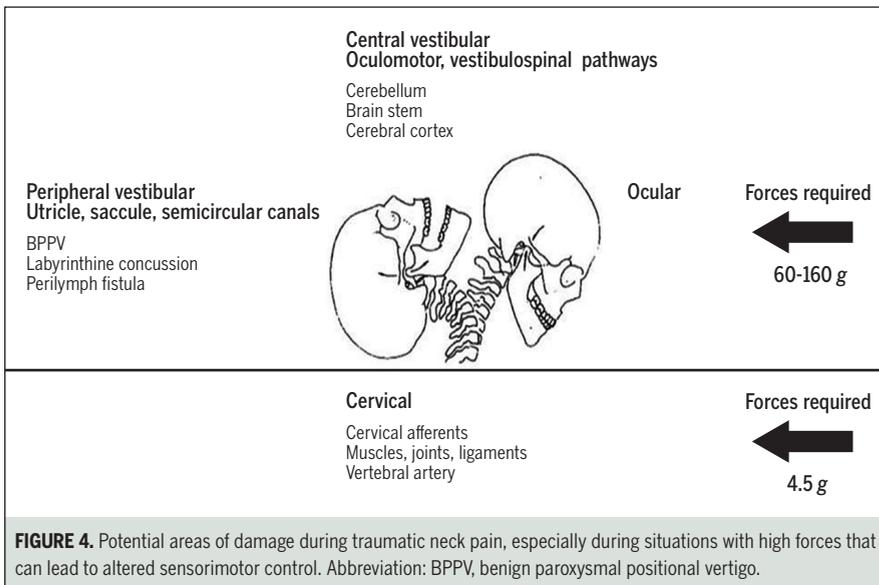


FIGURE 4. Potential areas of damage during traumatic neck pain, especially during situations with high forces that can lead to altered sensorimotor control. Abbreviation: BPPV, benign paroxysmal positional vertigo.

for vestibular migraine should also be considered in the chronic phase.^{63,64} Referral for a more thorough investigation of the vestibular, CNS, or visual systems and appropriate medical management may then be warranted.

At present, consensus opinion is that tests to identify vestibular or CNS dysfunction have stronger clinical utility than tests for cervical causes of dizziness and sensorimotor control disturbances.⁸⁷ Nevertheless, there are some emerging objective tests that may also help differential diagnosis of cervicogenic causes of the disturbances, with a cluster of tests likely to be more discriminatory than individual tests.⁶⁷ For example, tests of smooth pursuit,^{111,119} balance,¹³³ and JPS¹² in torsion (head still, trunk rotated) may be useful in indicating the extent of the cervical spine contribution to the deficits. This is expected when signs and symptoms are increased when the individual is positioned in torsion compared to the neutral neck position. Similarly, in a recent study, the cervical torsion test was found to be one of a cluster of useful discriminating tests for cervicogenic dizziness. In this test, the head is held still and the patient rotates the trunk to the left, then returns to neutral, then rotates the trunk to the right, and finally returns to neutral. Each position is sustained for 30 seconds, and nystagmus of greater than 2°/s in any of the 4 positions is considered a positive test.⁶⁷ Conversely, reproduction of symptoms during en bloc tests (ie, simultaneous trunk and head rotation) should indicate a noncervical cause.⁴⁹ Associated findings of musculoskeletal impairment in the cervical spine, especially the upper cervical spine, have been shown to be important in those with cervicogenic dizziness^{67,86}; however, this is usually present in those with traumatic neck pain and thus not specifically helpful for differential diagnosis in this group. A potential schema for differential diagnosis, possible subjective and objective test findings, and subsequent management that may be required are presented in the **TABLE**.

damage to many neck structures,¹⁰⁷ including the vertebral artery. Although vertebral artery dissection is rare, it is potentially dangerous^{9,56} and should always be considered in the differential diagnosis. Recent work by Thomas¹⁰⁸ and Thomas et al¹⁰⁹ suggests that this should be suspected, particularly in those with severe unilateral neck pain and headache and those who report transient or ongoing specific neurological dysfunction.

However, when higher forces or a direct blow to the head occur, additional injuries, such as concussion and/or damage to the CNS or visual or peripheral vestibular apparatus, are more likely (**FIGURE 4**).⁷⁴ It has been suggested that up to 35% of those with traumatic neck pain associated with higher forces may have peripheral vestibular damage (eg, benign paroxysmal positional vertigo, damage to the endolymphatic sac, or a perilymph fistula).^{25,31,43,112} Further, there is some suggestion that injuries induced by axial rotation versus linear acceleration during the accident may result in different types of neuro-otological injury.⁴⁰ Vestibular migraine might also be triggered by the injury associated with traumatic neck pain.^{65,72} Conversely, in those who have a primary diagnosis of concussion, associated neck trauma should also be considered as a potential cause of some symptoms.^{30,69} Thus,

the clinician should interview the patient and choose tests accordingly to consider these possible causes of the disturbances and to determine the most likely cause.

In general, cervicogenic dizziness should be episodic, have a close temporal relationship to neck pain, be brought on by specific neck movements or positions rather than whole-body movements or other factors such as increased intracranial pressure or anxiety, and be described as an unsteadiness or light-headedness, not vertigo. Thus, the description, temporal pattern, and aggravating factors of the symptoms,^{16,17,53,121} as depicted in the **TABLE**, can be useful to determine the need for additional tests, such as the head thrust or head impulse test, and head shaking nystagmus, dynamic visual acuity for peripheral vestibular pathology, or the Dix-Hallpike or head-roll maneuvers for benign paroxysmal positional vertigo.⁴⁹ Spontaneous and gaze-evoked nystagmus, as well as other oculomotor tests such as eye tracking, skew deviation, and saccades, may be required if central vestibular pathology or brain injury is suspected.^{38,49} Tests of accommodative function such as near-point convergence, often positive in those with concussion, should be included in those with visual symptoms exacerbated by eye movements alone.^{42,80} The diagnostic criteria

TABLE

DIFFERENTIAL DIAGNOSIS AND SUGGESTED MANAGEMENT OF SENSORIMOTOR CONTROL DISTURBANCES IN THOSE WITH TRAUMATIC NECK PAIN

	Cervical	Vertebral Artery	BPPV	Perilymph Fistula	Peripheral Vestibular	Central Vestibular	Psychological
Description	<ul style="list-style-type: none"> • Unsteadiness • Light-headedness 	<ul style="list-style-type: none"> • Fainting • Vertigo dizziness 	<ul style="list-style-type: none"> • Vertigo 	<ul style="list-style-type: none"> • Vertigo • Dysequilibrium • Motion intolerance 	<ul style="list-style-type: none"> • Vertigo • Unsteadiness • Motion intolerance 	<ul style="list-style-type: none"> • Dysequilibrium • Motion intolerance 	<ul style="list-style-type: none"> • Floating • Rocking • Fullness in head
Frequency	<ul style="list-style-type: none"> • Episodic 	<ul style="list-style-type: none"> • Episodic 	<ul style="list-style-type: none"> • Discrete attacks 	<ul style="list-style-type: none"> • Episodic/constant 	<ul style="list-style-type: none"> • Episodic vertigo • Constant unsteadiness 	<ul style="list-style-type: none"> • Varies 	<ul style="list-style-type: none"> • Varies
Duration	<ul style="list-style-type: none"> • Minutes to hours 	<ul style="list-style-type: none"> • Several seconds 	<ul style="list-style-type: none"> • Seconds 	<ul style="list-style-type: none"> • Constant 	<ul style="list-style-type: none"> • Seconds to minutes 	<ul style="list-style-type: none"> • Varies 	<ul style="list-style-type: none"> • Varies
Exacerbated	<ul style="list-style-type: none"> • Increasing neck pain • Neck movement 	<ul style="list-style-type: none"> • Sustained neck extension and/or rotation 	<ul style="list-style-type: none"> • Rolling in bed • Looking up • Lying down 	<ul style="list-style-type: none"> • Visual challenges • Increased intracranial or atmospheric pressure (eg, blowing nose) • Loud noises 	<ul style="list-style-type: none"> • Head positions or movement 	<ul style="list-style-type: none"> • Spontaneous or provoked 	<ul style="list-style-type: none"> • Stress • Anxiety • Hyperventilation
Relieved	<ul style="list-style-type: none"> • Decreasing neck pain 	<ul style="list-style-type: none"> • Neck back to neutral 	<ul style="list-style-type: none"> • Subsides if staying in provoking position 	<ul style="list-style-type: none"> • Avoiding above activities, rest 	<ul style="list-style-type: none"> • Head/body still 	<ul style="list-style-type: none"> • Varies 	<ul style="list-style-type: none"> • Relaxation
Associated symptoms	<ul style="list-style-type: none"> • Blurred vision • Nausea • Neck pain 	<ul style="list-style-type: none"> • Dysarthria • Hemiparesis • Dyesthesia • Diplopia • Dysphagia • Drop attacks • Nystagmus • Nausea • Numbness 	<ul style="list-style-type: none"> • Nausea • Vomiting 	<ul style="list-style-type: none"> • Unilateral tinnitus • Aural pressure • Hearing loss 	<ul style="list-style-type: none"> • Nausea • Vomiting • Hearing loss • Tinnitus • Ear fullness 	<ul style="list-style-type: none"> • Nausea • Imbalance • CNS signs 	<ul style="list-style-type: none"> • Lump throat • Heart palpitations • Tight chest
Suggested cause	<ul style="list-style-type: none"> • Abnormal cervical afferent input 	<ul style="list-style-type: none"> • VA dissection/insufficiency 	<ul style="list-style-type: none"> • Debris in endolymph 	<ul style="list-style-type: none"> • Leak of perilymph fluid into middle ear 	<ul style="list-style-type: none"> • Vascular injuries • Fractures 	<ul style="list-style-type: none"> • Brain stem • Cerebellum 	<ul style="list-style-type: none"> • Anxiety • Stress
Primary objective findings	<ul style="list-style-type: none"> • Cervical musculoskeletal impairments • JPE, >4.5° • Increased sway • Balanced neck torsion • Positive SPNT • Positive cervical torsion test • Positive trunk-head coordination test • Absence of other findings 	<ul style="list-style-type: none"> • Possible positive VBI tests • VAD: unilateral severe headache • Transient neurological disturbances relating to VA function 	<ul style="list-style-type: none"> • Positive Dix-Hallpike or head roll 	<ul style="list-style-type: none"> • Positive pressure test • Positive Valsalva test 	<ul style="list-style-type: none"> • Head impulse • Head-shake DVA 	<ul style="list-style-type: none"> • Spontaneous or gaze-evoked nystagmus • Oculomotor deficits* • Ataxia 	<ul style="list-style-type: none"> • None
Suggested treatment	<ul style="list-style-type: none"> • Cervical musculoskeletal and tailored sensorimotor 	<ul style="list-style-type: none"> • Referral to neurologist 	<ul style="list-style-type: none"> • Epley or BBQ roll maneuver 	<ul style="list-style-type: none"> • Referral to ENT • Surgery 	<ul style="list-style-type: none"> • Tailored vestibular rehabilitation, central adaptation, habituation • Cervical musculoskeletal and tailored sensorimotor as required 	<ul style="list-style-type: none"> • Tailored rehabilitation, oculomotor, vestibular, balance, and gait • Cervical musculoskeletal and tailored sensorimotor as required 	<ul style="list-style-type: none"> • Meditation • Mindfulness • Stress management • Cervical musculoskeletal and tailored sensorimotor as required

*Abbreviations: BBQ, barbeque; BPPV, benign paroxysmal positional vertigo; CNS, central nervous system; DVA, dynamic visual acuity; ENT, ear-nose-throat specialist; JPE, joint position error; SPNT, smooth-pursuit neck torsion; VA, vertebral artery; VAD, vertebral artery dissection; VBI, vertebral basilar insufficiency. *Oculomotor includes skew deviation, vergence, smooth pursuit, and saccades.*

IMPLICATIONS FOR MANAGEMENT

GIVEN THE ABOVE AND THE CLOSE connections and adaptations involved in the sensorimotor control system, management of these disturbances is likely to be multimodal and may need to address not only the primary causes but also secondary adaptive changes in the sensorimotor control system. It would seem that this should be tailored to the individual and based on his or her specific self-reports and objective findings (TABLE). Overlap in conventional management approaches may therefore occur, for example, making use of vestibular rehabilitation strategies, but again, the management approach is likely to be more effective if it is a problem-oriented, tailored, evidence-based approach. It should also be pointed out that when neck pain is associated with vestibular pathology, often there is a need to address the cervical musculoskeletal impairments so that the individual is able to effectively complete the exercises for vestibular rehabilitation, as often this requires repetitive fast head/neck motion. The authors of a recent study have indeed demonstrated the benefits of including a musculoskeletal intervention in those with peripheral vestibular pathology.¹³¹

Cervical Musculoskeletal Management

Several studies have demonstrated improvements in dizziness and/or sensorimotor control in those with traumatic neck pain following treatment only targeted to the cervical spine, which likely addressed some of the causes of altered cervical afferent input. Acupuncture has been shown to improve cervical JPS, dizziness,⁴⁶ and standing balance,³³ and improvements in dizziness and JPS have also been demonstrated following manual therapy.⁴⁶ Further, cervical muscle endurance training improved balance in individuals with whiplash.⁹⁹ Nevertheless, while a recent clinical trial focusing on specific neck muscle exercises combined with a behavioral approach dem-

onstrated improved dizziness in those with whiplash, many continued to have symptoms of dizziness and signs of balance impairment following the intervention.¹²³ Similarly, in a study of individuals with cervicogenic dizziness, while dizziness improved with manual therapy, changes in JPS and balance were negligible.^{85,86} These findings suggest that additional interventions directed toward these specific other impairments may need to be considered.

Addressing Adaptive Changes in the Sensorimotor Control System

There is some evidence that specific treatment programs that emphasize gaze stability, eye-head coordination, and/or head-on-trunk relocation, without including local cervical spine treatment, have resulted in improvements not only in sensorimotor impairments but also in neck pain and/or perceived disability in those with traumatic neck pain.^{52,102,116} Vestibular rehabilitation programs have been shown to be useful in those with concussion^{1,45} and resulted in improved balance and dizziness in individuals with WAD.²⁷ Interestingly, in those with WAD, this training did not improve neck pain or movement.²⁸ Thus, such an approach provided in isolation may not be able to address all of the deficits or be the most efficient approach.

Combined Cervical Musculoskeletal Treatment and Structured Sensorimotor Approach

Studies that have included eye-head coupling and coordination exercises as part of a multimodal approach have demonstrated improvements in neck pain and JPS.^{46,84} A pilot trial of a combined approach demonstrated significant improvements in postural stability in those with chronic whiplash.⁷⁵

Combined Cervical Musculoskeletal and Tailored Sensorimotor Approach

While a combined approach may be more suitable, the lack of direct correlation between sensorimotor measures^{103,118}

would imply that treatment directed towards improving, for example, eye movement control may not necessarily be the most effective to improve balance or JPS. Thus, a tailored sensorimotor approach with exercises aimed to improve identified deficits in cervical joint position and movement sense, oculomotor function, and static and dynamic balance may be superior and is currently recommended clinically.^{55,114,115} A similar combination of cervical musculoskeletal and vestibular interventions has been shown to decrease time to return to sport in young adults with persistent symptoms of dizziness, neck pain, and headaches following concussion.⁹³ Others agree that this combined tailored approach would seem most suitable in those with concussion with associated neck trauma.^{10,30,69} Recently, an opinion piece also highlighted the potential of vision therapy as a component in the management of these patients.⁶ This area of research is in its infancy and should be considered in future studies.

CONCLUSION

THERE IS CONSIDERABLE EVIDENCE to support the importance of cervical afferent dysfunction in the development of dizziness, unsteadiness, visual disturbances, and altered balance, eye, and head movement control following neck trauma, especially in those with persistent pain. A thorough evaluation is required to also consider other possible causes and secondary adaptive changes in the process of differential diagnosis. It is important that such symptoms and impairments be adequately assessed and tailored management be implemented. This should become an essential part of the routine assessment and management of those with traumatic neck pain, including those with concomitant injuries such as concussion, vestibular system damage, and visual pathology or deficits. Ongoing research to assist differential diagnosis and to understand the most important contributing factors associated with abnormal cervical input

and subsequent disturbances to the sensorimotor control system, as well as the most efficacious management of such symptoms and impairments, continues to add to our knowledge. ●

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