Masterclass

Sensorimotor disturbances in neck disorders affecting postural stability, head and eye movement control

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Abstract

The receptors in the cervical spine have important connections to the vestibular and visual apparatus as well as several areas of the central nervous system. Dysfunction of the cervical receptors in neck disorders can alter afferent input subsequently changing the integration, timing and tuning of sensorimotor control. Measurable changes in cervical joint position sense, eye movement control and postural stability and reports of dizziness and unsteadiness by patients with neck disorders can be related to such alterations to sensorimotor control.

It is advocated that assessment and management of abnormal cervical somatosensory input and sensorimotor control in neck pain patients is as important as considering lower limb proprioceptive retraining following an ankle or knee injury. Afferent information from the cervical receptors can be altered via a number of mechanisms such as trauma, functional impairment of the receptors, changes in muscle spindle sensitivity and the vast effects of pain at many levels of the nervous system. Recommendations for clinical assessment and management of such sensorimotor control disturbances in neck disorders are presented based on the evidence available to date.

Keywords: Sensorimotor; Eye; Head; Postural stability; Cervical; Management

1. Introduction

Sensorimotor control of stable upright posture and head and eye movement relies on afferent information from the vestibular, visual and proprioceptive systems, which converge in several areas throughout the central nervous system. The cervical spine has an important role in providing the proprioceptive input and this is reflected in the abundance of cervical mechanoreceptors and their central and reflex connections to the vestibular, visual and central nervous systems.

Muscle spindles in the cervical region are found in high densities especially in the suboccipital region where there are up to 200 muscle spindles per gram of muscle. This number is considerable when compared to the first lumbrical in the thumb where there are 16 muscle spindles per gram (Kulkarni et al., 2001; Boyd Clark et al., 2002; Liu et al., 2003). The cervical muscles, especially the suboccipital muscles, relay information to and receive information from the central nervous system and there are specific connections between the cervical receptors and the visual and vestibular apparatus and the sympathetic nervous system (Selbie et al., 1993; Bolton et al., 1998; Corneil et al., 2002; Hellstrom et al., 2005). The cervical afferents are also involved in three reflexes influencing head, eye and postural stability: the cervico-collic reflex (CCR), the cervico-ocular reflex (COR) and the tonic neck reflex (TNR). These reflexes work in conjunction with other reflexes, which are influenced by vestibular and visual input for coordinated stability of the head, eyes and posture. The CCR activates neck muscles in response to stretch to assist in the maintenance of head position (Peterson, 2004). The COR works with the vestibulococular reflex and optokinetic reflex, acting on the extraocular muscles, to assist
clear vision with movement (Mergner et al., 1998).
The TNR is integrated with the vestibulospinal reflex
to achieve postural stability (Yamagata et al., 1991)
(Fig. 1).
The importance of the cervical central and reflex
connections can be realized from response to artificial
disturbances to the cervical afferents in asymptomatic
individuals. Sectioning of the cervical nerves or anaes-
thetic injections into the neck causes nystagmus,
disequilibrium and severe ataxia (DeJong and DeJong,
1977; Ishikawa et al., 1998). Vibration of neck muscles,
which is thought to stimulate muscle spindle afferents,
induces several disturbances in asymptomatic indi-
viduals including changes to eye and head position,
alterations to body sway and the velocity and direction
of gait and running (Lennerstrand et al., 1996; Bove
et al., 2002; Courtine et al., 2003). Similar effects have
been demonstrated by either simple isometric neck
muscle contractions or induced neck muscle fatigue
(Gosselin et al., 2004; Schmid and Schieppati, 2005;
Vuillerme et al., 2005). Such disturbances are thought
to result from a mismatch between abnormal information
from the cervical spine and normal information from the
vestibular and visual systems.

2. Disturbances in sensorimotor control in neck disorders

Considering the experimental evidence, it is not
 surprising that disturbances in cervical joint position
sense (JPS) (Revel et al., 1991; Heikkila and Astrom,
1996; Treleaven et al., 2003), postural stability (Karlberg
et al., 1996; Sjostrom et al., 2003; Treleaven et al.,
2005a, b; Field et al., 2007) and oculomotor control,
such as altered smooth pursuit and saccadic eye move-
ment (Tjell et al., 2003; Treleaven et al., 2005a, b; Storaci
et al., 2006), can present in patients with neck disorders
of either an insidious or traumatic nature as a result of
cervical somatosensory dysfunction. An increased gain
of the cervico-ocular reflex has also been demonstrated
in patients with whiplash (Montfoort et al., 2006).
Altered smooth pursuit neck torsion control occurs in
neck pain subjects (both idiopathic and traumatic) but
not in those with vestibular disorders and central
nervous system dysfunction. Smooth pursuit neck
torsion control is a difference in eye movement control
when measured with the neck in torsioned (i.e., trunk
turned 45° but the head remains neutral compared to a
neutral head, neck and trunk position) and supports the
premise of neck afferent dysfunction as the cause of the
smooth pursuit eye movement disturbances (Tjell and
Rosenhall, 1998; Tjell et al., 2003; Treleaven et al.,
2005a, b).

Complaints of dizziness and or unsteadiness can also,
but not necessarily, occur in patients with chronic
cervical headache and persistent whiplash-associated
disorders (Treleaven et al., 2003; Jull et al., 2007). Some
neck pain patients also report visual complaints, loss of
balance and actual falls (Hulse and Holzl, 2000;
Treleaven et al., 2003). Cervical vertigo is considered a
principle cause when associated with a whiplash injury
(Wenngren et al., 2002; Treleaven et al., 2006) but other
causes of dizziness and unsteadiness should be considered, such as damage to the vertebral artery, vestibular receptors or central nervous system, elevated anxiety or medication intake (Balogh and Halmagyi, 1996; Ernst et al., 2005; Sturzenegger et al., 1994). Greater deficits in tests of head and eye movement control and postural stability have been measured in patients with neck disorders of traumatic origin, in association with the complaint of dizziness (Tjell et al., 2003; Treleaven et al., 2003, 2005a, b), although these deficits can present in the absence of dizziness as well as in patients with idiopathic neck pain (Kristjansson et al., 2003; Tjell et al., 2003; Field et al., 2007). Although the causes of the disturbances are similar it has been shown that an individual patient may present with dysfunction in either one or several systems. For example, an individual patient may have moderate disturbances to eye movement control but not necessarily have the same degree or any disturbance in cervical JPS or balance (Treleaven et al., 2006).

It would appear that either decreased or increased cervical somatosensory activity can result in disturbances of sensorimotor function (Hinoki and Niki, 1975; DeJong and DeJong, 1977). This occurs via a number of mechanisms (Fig. 2). Cervical mechanoreceptor function could be altered as a result of direct trauma to mechanoreceptors (Loescher et al., 1993; Chen et al., 2006), functional impairment of muscles such as increased fatigability (Falla, 2004) or degenerative changes in the muscles such as fibre transformation, fatty infiltration and muscle inhibition or atrophy (Uhlig et al., 1995; McPartland et al., 1997; Kristjansson et al., 2004; Elliott et al., 2006). In addition, the effects of pain at many levels of the nervous system can change muscle spindle sensitivity and alter the cortical representation and modulation of cervical afferent input (Le Pera et al., 2001; Thunberg et al., 2001; Flor, 2003). Psychosocial stresses might also alter muscle spindle activity via activation of the sympathetic nervous system (Passatore and Roatta, 2006).

It is likely that several processes combine to cause an immediate and sustained alteration in somatosensory function originating from the cervical spine, which influence the tuning and integration of input within the sensorimotor control system. Secondary impairment of vestibular system functioning might also occur (Fischer et al., 1997) and this has implications for management of such disturbances in neck disorders. The majority of the research into sensorimotor control disturbances has been undertaken in patients with persistent neck pain, however there is evidence that deficits could occur soon after the onset of pain (Sterling et al., 2003) and may have an influence on prognosis (Hildingsson et al., 1993). Thus, routine assessment of head and eye movement control and postural stability in neck disorders is recommended.

Evidence to date would suggest that management of disturbed sensorimotor control due to cervical somatosensory dysfunction might need to address the primary causes of the altered somatosensory activity as well as secondary effects. Specific treatments to the neck such as acupuncture, manual therapy and cranio-cervical flexion training have improved cervical joint position error, vertigo and/or standing balance in patients with neck pain (Fattori et al., 1996; Heikkila et al., 2000; Reid and Rivett, 2005; Palmgren et al., 2006; Jull et al., 2007). Alternatively, programs that emphasize gaze stability, eye/head co-ordination and cervical position sense without local cervical spine treatment have resulted in decreased medication intake, improved neck pain and disability and cervical joint position sense (Revel et al., 1994; Humphreys and Irgens, 2002; Jull et al., 2007).
Improvements in balance and symptoms of dizziness have also been observed following a vestibular or oculomotor rehabilitation program in patients with persistent whiplash (Hansson et al., 2006; Storaci et al., 2006). Currently local treatment to the cervical spine in conjunction with tailored programs for sensorimotor control is recommended for patients with neck disorders. The tailored sensorimotor program is similar to that used in vestibular rehabilitation (Herdman, 2000). This combined approach will address the local causes of abnormal cervical afferent input and consider the important links between the cervical, vestibular and ocular systems and any secondary adaptive changes in the sensorimotor control system.

3. Clinical assessment of sensorimotor control disturbances in neck disorders

Based on the evidence to date, the assessment of sensorimotor control in the neck pain patient should include: investigation of the symptom of dizziness and unsteadiness and measurement of cervical joint position error, postural stability and oculomotor control. The clinician though should be aware of other possible causes of the disturbances and interview the patient and choose tests accordingly to determine the most likely cause. With respect to dizziness, the description, temporal pattern, associated symptoms and history of the complaint of dizziness can be useful in assisting differential diagnosis of cervicogenic dizziness. Other symptoms such as visual complaints (blurred vision, words jumping and unclear contours of objects) loss of balance, actual falls, difficulty walking in the dark, on stairs or negotiating doorways should be noted. The Dizziness Handicap Inventory Short Form Questionnaire (Tesio et al., 1999) can be used to quantify the functional impact of the dizziness. The physical examination may include measures of cervical joint position sense, postural stability and oculomotor control as indicated. In research, precise measurements are taken of these features. However, they can be assessed satisfactorily in the clinical situation albeit with lesser precision.

3.1. Cervical joint position sense (JPS)

A simple measure for cervical JPS is the use of a small laser pointer or torch mounted onto a lightweight headband as used by Revel et al. (1991) (Fig. 3). The patient is seated 90 cm from a wall and the starting point projected by the laser is marked. The patient (blindfolded or eyes closed) performs an active neck movement and then returns as accurately as possible to the starting position. The final laser position is measured against the starting position in centimeters. This method provides a quantitative assessment tool as errors as little as 3–4° (4–5 cm) can indicate a deficit in cervical JPS (Revel et al., 1991; Treleaven et al., 2003). Errors are measured following active return from cervical extension, flexion and rotation. Relocating to selected points in range (Loudon et al., 1997) and accuracy in retracing patterns (Kristjansson et al., 2004) can also be used to assess cervical kinaesthesia. Jerky movements, searching or overshooting the initial position, reproduction of dizziness and/or a noticeable difference of cervical movement patterns in the test with eyes closed may also indicate impaired cervical kinaesthetic sense.

3.2. Oculomotor

Oculomotor assessment incorporates assessment of gaze stability (the ability to maintain gaze while moving the head), smooth pursuit (eye follow while keeping the head still), saccadic eye movement (rapid eye movements to change a point of fixation) and eye/head coordination (maintaining gaze when both the eyes and head are moving). The tests are usually performed with the patient in a sitting position but can be tested initially in supine lying if necessary. The starting position will depend on the severity of the patient’s complaints and overall physical findings.

3.2.1. Gaze stability

Gaze stability is assessed by asking the patient to keep the eyes focused on a target while actively moving the head into flexion, extension and rotation (Fig. 4). Inability to maintain focus on the target, reduced or
awkward cervical motion or reproduction of symptoms such as dizziness, blurring of vision or nausea are signs of an abnormal response.

3.2.2. Eye follow
The patient keeps the head still while following a moving target with the eyes as closely as possible. The target is moved slowly side to side (20°/s through a visual angle of 40°). The test is repeated with the head still but with the trunk rotated up to 45° (Fig. 5). The test is repeated on the opposite side. Any difference is noted in smooth eye follow or symptom reproduction in these neck torsion positions compared to the neutral position. Often patients with neck disorders will be unable to keep up with the target and demonstrate quick catch up eye movements when the neck is in torsion particularly when the target is crossing the midline. Saccadic eye movements at the extremes of the visual angle and with the change of movement direction are not considered abnormal.

3.2.3. Saccadic eye movement
The patient follows and fixes their gaze on a target that is quickly moved and then held still momentarily. The target is moved in several different directions. The patient’s ability to quickly move to the target and fixate on it is noted.

3.2.4. Eye/head co-ordination
The patient moves the eyes and head in the same direction to focus on a point, leading with the eyes first to a target and then the head ensuring the eyes keep focused on the target. This can be performed to the left, right and up and down.

3.3. Postural stability
A modified sensory organization test is used to assess postural stability. Visual and proprioceptive input from the lower limbs is altered as the tests progress (Shumway-Cook and Horak, 1986). Balance in comfortable and narrow stance can be assessed with the patient standing on a firm and then a soft surface such as a piece of 10 cm dense foam. The tests should be performed with both eyes open and closed. Inability to maintain stance for 30 s, noticeably large increases in sway, slower responses to correct sway or rigidity to prevent sway are
considered abnormal responses. It is thought that people with neck disorders rely more on vision and other somatosensory inputs for balance and thus deficits will be greatest when these inputs (e.g., vision) are reduced. For increasing challenge, the patient can be tested in tandem and then single leg stance on a firm surface with eyes open and closed. It is reasonable to expect that a person under the age of 60 years can maintain stability for up to 30 s in the comfortable and narrow stance tests. Subjects under 45 years should also be able to complete tandem and single leg stance tests. (Treleaven et al., 2005a, b) Assessment of the ability to complete the 30 s of the tandem stance can be a useful screening test (Treleaven et al., 2005a, b; Field et al., 2007).

3.4. Additional tests

There is some evidence that the neck may directly influence vestibular functioning (Fischer et al., 1997). In addition, primary vestibular pathology is also possible following a whiplash injury or in the middle aged/elderly population. Thus, assessment of postural control disturbances may need to address secondary vestibular influences on postural control. While there is certainly overlap between cervical and vestibular systems in a number of the testing procedures already described, additional tests to investigate vestibular function more closely may be necessary in some neck pain patients, especially those complaining of loss of balance and falls. Factors such as ageing, pre-existing vestibular pathology and medical conditions might increase the degree of disturbances in those with neck disorders (Poole et al., 2007). Additional tests might include tests of dynamic balance and functional ambulation (Herdman, 2000; Alpini et al., 2005), as well as testing of the vestibulocular reflex (Herdman, 2000). In cases where Benign Paroxysmal Positional Vertigo is suspected the Hallpike-Dix manoeuvre should be included (Herdman, 2000). Referral for a more thorough investigation of the vestibular or central nervous system may be warranted in those where cervical causes of the disturbances cannot be substantiated.

4. Management of sensorimotor control disturbances in neck disorders

The findings of the assessment will direct and tailor the most appropriate management of sensorimotor control disturbances in the individual patient with a neck disorder. It is suggested that management include both local treatment to the neck to decrease pain and improve neuromuscular function in combination with tailored sensorimotor exercises to improve any deficits in cervical JPS, oculomotor control and postural stability. This addresses the causes of abnormal cervical mechanoreceptor input as well as the effects resulting from the potential conflict arising from abnormal cervical afferent input and normal vestibular and ocular input.

Exercises for each system should be performed two to five times per day. Temporary reproduction of dizziness is acceptable however exacerbation of neck pain or headache is not acceptable. If this occurs the exercises should be modified by decreasing the number of repetitions or altering the patient position to a more supported position such as supine lying. Progression of each exercise set can be achieved by altering the duration, repetitions and the degree of difficulty of the task. Exercises can also be progressed by performing activities such as an eye task or cervical JPS practice while sitting on an unstable surface or while standing with the feet in an unstable base of support for example, heel toe stance, or while walking. Some examples follow.

4.1. Cervical joint position sense

The patient practices relocating the head back to the natural head posture and to pre-determined positions in range from the movement directions assessed to be abnormal. The patient may practice first with the eyes open and then with eyes closed, lining up their natural head posture and target positions with points on the wall to check their accuracy on return. The exercise can be made more precise for home use with the use of a pencil torch or laser attached to a headband. Higher level skills training could include tracing intricate patterns, such as a figure of 8 placed on the wall, with the head using the head torch or laser for feedback.

4.2. Oculomotor exercises

The exercise level is set on the basis of the oculomotor assessment. The degree of difficulty for oculomotor exercises can be increased by increasing the speed of the task, range of motion, changing the patient’s position and the focus point or background (Fig. 6). Table 1 outlines how each of the various variables can be altered to progress the exercises.

4.2.1. Eye follow with a stationary head

The patient eyes follow a target moving side to side and up and down keeping the head still. For home use, the patient could practice tracking a tennis ball tossed sideways or up and down whilst keeping the head still.

4.2.2. Saccadic eye movements

Saccadic movements of a target are performed at randomised eye positions. Progress can include increasing the speed of the movements, position of the patient and the visual background or focus point (Table 1).
4.2.3. Gaze stability

Training may commence with the clinician performing slow passive neck movements or the patient performing active neck movements, while they fixate their gaze on a point on the ceiling. The clinician can also passively move the trunk while the patient maintains gaze on a target. The patient can be asked to fix their gaze on a point, close their eyes and perform a neck movement and open their eyes after the head movement to check for stable gaze on the target. Any task may be progressed by restricting peripheral vision, using a pair of swimming goggles that have been blackened out except for a small area in the center of each side.

4.2.4. Eye/head co-ordination

The exercises commence with rotating the eyes and head to the same side, in both left and right and up and down directions. As a progression, the eyes are moved first, then the head, but the patient continues to maintain focus on two targets which can be positioned horizontally or vertically. Further progression could include the patient performing active neck rotation to follow a slow moving target while their peripheral vision is restricted. The patient can also practice rotating the eyes and head to look as far behind as possible. Active movements of the head to follow a moving target can be performed both with unrestricted and peripheral restricted movement.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Start</th>
<th>Progress</th>
<th>Further progression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target</td>
<td>Single spot</td>
<td>Word</td>
<td>Business card</td>
</tr>
<tr>
<td>Background to target</td>
<td>Plain</td>
<td>Stripes</td>
<td>Checker board</td>
</tr>
<tr>
<td>Patient position</td>
<td>Supine—sitting</td>
<td>Standing—vary stance</td>
<td>Walking</td>
</tr>
<tr>
<td>Neck position</td>
<td>Neutral</td>
<td>Torsion 30°</td>
<td>Torsion 45°</td>
</tr>
<tr>
<td>Speed</td>
<td>Slow</td>
<td>Medium</td>
<td>Fast</td>
</tr>
<tr>
<td>Vision</td>
<td>Unrestricted</td>
<td>Restricted peripheral</td>
<td>Restricted peripheral</td>
</tr>
<tr>
<td>Range of motion</td>
<td>Small</td>
<td>Medium</td>
<td>Large</td>
</tr>
<tr>
<td>Duration of exercise</td>
<td>30s</td>
<td>1-2 min</td>
<td>5 min</td>
</tr>
<tr>
<td>Frequency of exercise</td>
<td>2 × day</td>
<td>3 × day</td>
<td>5 × day</td>
</tr>
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Fig. 6. Progression of eye exercises by altering either the focus point or the background of the focus point.

Table 1
Various methods of progression of the oculomotor exercises

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4.3. Postural stability

The starting level for balance retraining will depend on which tests the patient failed or had difficulty with in the clinical assessment. This could be comfortable, narrow, tandem or single leg stance. The conditions for training progress from eyes open, eyes closed to different supporting surfaces. Patients practice the exercise at home perhaps in a corner area, such that they are able to regain balance easily if necessary (Fig. 7). They gradually increase the time of maintaining stability to reach 30 s. Challenges to the system can be increased with the addition of relocation practice or oculomotor exercises to the balance exercise. Walking forwards, backwards and sideways while actively moving the head into different directions, maintaining direction and velocity of gait, also challenge cervical afferent input for balance mechanisms.

5. Conclusion

Given the importance of the neck for postural stability, head and eye movement control, as well as the nature of the changes in sensorimotor control seen in those with neck disorders, assessment and management of such disturbances should form an important part of the multimodal approach to neck disorders. This should include addressing the causes of the altered cervical somatosensory input such as improving neuromuscular function and decreasing pain and inflammation as well as a tailored sensorimotor exercise program to improve identified deficits in postural stability and head and eye movement control. The recommended clinical assessment and management is based on the available evidence to date; however, this is an emerging area and more extensive research is needed to refine and identify methods for assessment and determine the optimal strategies for management of such disturbances in patients with neck disorders.

There will be a case study published online to support this Masterclass at a later date.

References


comparison between subjects with and without dizziness. Journal
error to balance and eye movement disturbances in persistent
in neck muscles of patients with dysfunction of the cervical spine.
Vuillerme N, Pinsault N, et al. Postural control during quiet standing
following cervical muscular fatigue: effects of changes in sensory
Wenngren B, Pettersson K, et al. Eye motility and auditory brainstem
response dysfunction after whiplash injury. Acta Orthopaedica
Yamagata Y, Yates BJ, et al. Participation of Ia reciprocal inhibitory
neurons in the spinal circuitry of the tonic neck reflex. Experi-