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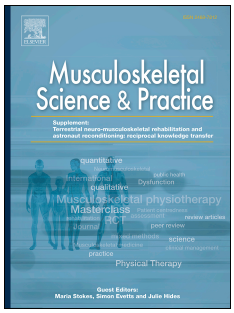

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PII: S2468-7812(17)30142-X

DOI: 10.1016/j.msksp.2017.08.010

Reference: MSKSP 115

To appear in: *Musculoskeletal Science and Practice*

Received Date: 3 February 2017

Revised Date: 7 August 2017

Accepted Date: 23 August 2017

Please cite this article as: Giffard, P., Daly, L., Treleaven, J., Influence of neck torsion on near point convergence in subjects with idiopathic neck pain, *Musculoskeletal Science and Practice* (2017), doi: 10.1016/j.msksp.2017.08.010.

INFLUENCE OF NECK TORSION ON NEAR POINT CONVERGENCE IN SUBJECTS WITH IDIOPATHIC NECK PAIN

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ABSTRACT

Background: People with neck pain (NP) experience sensorimotor and oculomotor deficits thought to be due to abnormal cervical afferent input. Convergence insufficiency (CI) measured by near point convergence (NPC) may be a feature in NP and neck torsion might help to differentiate a cervical cause.

Objectives: This study aimed to investigate repeatability and reliability of NPC in neutral and torsion and compare between idiopathic NP and controls along with correlation to the Convergence Insufficiency Symptom Survey (CISS).

Design: Comparative cross sectional observational study.

Method: A Royal Airforce (RAF) Rule measured NPC with the neck in neutral and in 45 degrees torsion to the left and right in 42 subjects. A revised 15 item CISS was also completed. The average of 3 trials in each position and torsion difference were calculated. Within one week, NPC inter-rater and test-retest reliability was evaluated in 10 subjects.

Results: A significant NPC torsion difference was demonstrated in participants with NP compared to controls (P=0.01). No significant differences were seen for NPC values in neutral (P=0.73). High inter-rater reliability (ICC=0.95) and repeatability (ICC=0.84) was obtained. No correlations were present between the CISS and NPC measures ($r \leq 0.18$).

Conclusions: NPC is impaired in neck torsion compared to neutral in NP supporting a cervical afferent cause. NPC, measured using the RAF Rule, is a reliable and repeatable measure and can be used to assess NPC and CI in those with NP. Objective rather than self-reported measures should be used to examine CI in NP.

Key Words: Neck Pain, Near Point Convergence, CISS, torsion

INTRODUCTION

The neck has a high percentage of proprioceptors and reflex connections to the eyes and inner ear, which provide input to the sensorimotor system to control head and eye movement and postural stability (Peterson et al., 1985; Treleaven, 2008). Specific to eye movement control is the cervical connections to the superior colliculus, which is the centre for head eye co-ordination (Corneil et al., 2002).

Around 30-50% of the adult population experience NP during one year (Guzman et al., 2008). Visual disturbances are common in those with neck pain NP with at least 50% reporting one visual symptom (Treleaven et al., 2014) which are thought to relate to deficits in oculomotor control (Treleaven et al., 2005a; Treleaven et al., 2011c) due to abnormal cervical afferent input (Kristjansson et al., 2009).

To date, deficits in saccadic (Heikkila et al., 1998; Mosimann et al., 2000) and smooth pursuit eye movements (Treleaven et al., 2005a; Treleaven et al., 2011a) and ocular reflexes (Montfoort et al., 2006; de Vries et al., 2016) have been demonstrated in those with traumatic and or idiopathic neck pain (INP). These tests consider both eyes moving in the same direction, but little consideration has been given to tests examining eyes moving in the opposite direction, for example during convergence (McGregor, 2014). One small study found a greater percentage of convergence abnormalities compared to saccadic and smooth pursuit eye movement abnormalities in those with persistent neck pain following a whiplash injury (WAD) (Burke et al., 1992).

Convergence Insufficiency (CI) can be examined by testing near point convergence (NPC) using simple equipment such as the Royal Airforce (RAF) Rule (Siderov et al., 2001; Adler et al., 2007). An objective measure of NPC is likely to be important as there is debate as to the suitability of self-reported scales such as the Convergence Insufficiency Symptom Survey (CISS) to identify those with CI (Rouse et al., 2004).

Currently, there are no known studies analysing NPC, the RAF Rule, or the CISS in those suffering from persistent INP. Examining the repeatability and reliability of the RAF Rule as a method of testing NPC, and comparing results to those depicted in the CISS, will evaluate these methods of measurement in an adult population as well as analyse the suitability of these measures in INP patients.

Further, as visual disturbances can be due to several causes, keeping the head still over a rotated trunk, in a process known as neck torsion, has successfully been used to differentiate vestibular and central nervous system versus cervical causes in smooth pursuit eye movement control tests (Tjell et al., 1998; Treleaven et al., 2008). Thus it is likely that CI could occur in INP and this may be influenced by neck torsion.

Thus the primary aim of this paper was to determine whether, participants with INP have abnormal NPC, influenced by altering cervical afferent input using the neck torsion manoeuvre, compared to controls. The secondary aim of the study was to determine if using the RAF Rule to assess convergence is a repeatable and reliable test in this population.

The final aim was to establish whether CI examined practically by a RAF Rule, positively correlated with scores on the revised 15 item CISS.

It was hypothesised that compared to asymptomatic individuals, INP participants will have increased NPC in neck torsion compared to head neutral, that the RAF rule will be a valid and reliable measure of NPC in this population and there will be poor correlation between NPC values and the CISS.

METHODS

Design

Comparative cross sectional observational study.

Participants

Over a fifteen-week period, volunteers who met the inclusion/ exclusion criteria aged 18 to 65 were recruited from 'X' and the wider community using flyers and online advertising. Participants with INP were included if they presented with a Neck Disability Index Score (NDI) ≥10% (Vernon, 1996), had experienced NP of varying intensity in the previous three months and possessed at least 45 degrees of cervical rotation to both the left and right.

Exclusion criteria for participants with INP included; experiencing a previous head injury or cervical dislocation/fracture, having diagnosed eye movement disorders or disease, possessing a vestibular/inner ear pathology, neurological disorder, strabismus, trochlear nerve injury, previously diagnosed CNS disease, ear or eye surgery, deafness, impaired visual acuity, dizziness experienced due to vascular causes and wearing bifocals, trifocals or graduated lenses. Healthy controls were excluded if they suffered NP in the previous three months, had a history of chronic head/NP or trauma, had strabismus, presented with an NDI ≥10% or wore bifocals, trifocals or graduated lenses.

Ethical clearance for this study was granted from the Human Medical Research Ethics Committee of the XXX and all participants provided informed written consent prior to testing.

Measurements

A Richmond Products, 537800 model RAF Rule was used to measure Near Point Convergence (NPC) break and recovery points (Adler et al., 2007).

A questionnaire was distributed to all participants collecting demographic data and information regarding NP specifics, such as location using a body chart, frequency of dizziness and any current medications.

Included validated questionnaires consisted of:

Neck Pain Disability Index (NDI) which was scored as a percentage and is a reliable indicator of NP and disability (Vernon, 1996). The individual NDI item regarding reading score/5 was also recorded.

Dizziness Handicap Index short form (DHIsf) consists of 13 items measuring the level of handicap associated with the symptom of dizziness. A Yes (0) or No (1) response to each item is required, where a score of 13 denotes no disability and a score of 0 indicated maximal disability due to dizziness (Tesio et al., 1999).

Vision Symptom Survey (VSS) was based on a proforma used in previous research (Treleaven et al., 2014). It included items relating to visual disturbances or complaints. These were both vision specific items (eg ‘red eyes’, ‘itchy eyes’, ‘squinting’, ‘heavy eyes’, ‘spots in eyes’) and vision related items (eg ‘fatigue’, ‘light sensitivity’, ‘need to concentrate to read) (Treleaven et al., 2014). Each of the 14 items were scored as the product of the indicated severity (0-3) and frequency (0-4) with the items then summed for a maximal total of 168, with higher scores indicating greater visual disturbances. (Treleaven et al., 2014).

The revised 15 item Convergence Insufficiency Symptom Survey (CISS) version was used to examine 15 symptoms to quantify the severity of symptoms associated with CI when reading

and doing close work (Rouse et al., 2004). Each item was scored from 0-4 with the sum of the items used as a total score/60 with higher scores indicating greater CI and values ≥21 thought to be associated with CI. Validity and reliability of the CISS has been established in adults. (Rouse et al., 2004).

Dizziness and neck pain intensity: A 0-100 mm visual analogue scale (VAS) was used to investigate the average neck pain and dizziness intensity during the last week. Higher scores indicate greater intensity (0= no pain, 100= worst pain imaginable).

Measurement Protocol

Each subject completed the questionnaires and then sat on a chair with back support and a rotating cushion seat enabling the participant to turn. This chair was placed 1.25 metres (m) from the wall on top of a plastic mat with markers drawn to indicate 45 degrees to the left and right (Figure 1).

Fig. 1. Experimental set-up with rotating cushion seat and markers on a plastic mat indicating 45 degrees to the left and right. The line on the centre of the rotating cushion was matched to the 45 degree line on the mat to allow consistency with the rotated position.

Subjects wore their usual corrective vision devices to see an object clearly at 50 centimetres (cm) and held the black cheek rest of the RAF Rule underneath their eyes whilst the clinician stabilised the other end. Participants were instructed to focus with both eyes on an image, (vertical line with a small dot in the middle), tilted down at 15 degrees.. The target was then

moved towards them at approximately 2cm per second from a starting position of 50cm. The subject was instructed to notify the clinician when diplopia (the single line became 2 distinct lines) occurred (subjective NPC break point) (Figure 2a). (Adler et al., 2007).

Fig. 2a. Near point convergence being measured by the Royal Airforce Rule with the subject in a neutral position.

Fig. 2b. Near point convergence being measured by the Royal Airforce Rule with the subject in a torsion position to the left.

Only subjective values were documented as previous studies indicated that objective and subjective break produced the same results (Siderov et al., 2001; Adler et al., 2007). This procedure was performed with participants sitting with their head and trunk in a neutral position as well as in a neck torsion position to the left and right (Figure 2b). Torsion NPC measures were obtained directly following those in neutral. Placing the subject's neck in torsion involved the examiner gently holding the head still whilst the patient turned their trunk 45 degrees to the left or right. A laser situated on the patient's head pointing directly towards a target located 1.05m above the ground, provided a visual cue for each participant and the examiner to maintain a static central head position whilst the trunk was turned.

Three repetitions of each measure were performed. Convergence values NPC were documented on a recording sheet in centimetres rounding to the nearest 0.5cm (Siderov et al., 2001; Adler et al., 2007). Visual corrective devices required during the test and any symptoms post testing were documented at the conclusion of the NPC examination.

Inter-rater Reliability and Repeatability

Test-retest and inter-rater reliability were examined using 10 (3 INP and 7 control) subjects. To satisfy inter-rater reliability requirements, another clinician performed the identical test on participants immediately following the initial test executed by clinician 1. Test-retest reliability was analysed with clinician 1 performing the same investigation on these participants within one week at a similar time of day as the original examination.

Data Management and Statistical Analysis

An average of the 3 trials was calculated for the NPC break point repetitions performed in each of the testing positions for every participant. The average torsion value was the mean of both the left and right NPC break point torsion scores. Torsion difference was computed by subtracting the average NPC break point measure in neutral from the average torsion value. Subtracting the average NPC break point in neutral from the average NPC break point in left or right torsion, resulted in left or right torsion difference.

Data were analysed using version 22 of Statistical Package for the Social Sciences IBM corp. Normality was assessed using a QQ plot, histogram, box and whisker plot and descriptive statistics including mean and median analysis. Fishers exact tests were employed for differences in proportion of gender (male/ female) and visual aid use (yes or no) between the NP and asymptomatic groups. A Mann-Whitney U Test was implemented to evaluate age

and questionnaire data as the data were not normally distributed. Following the satisfaction of the normality assumption for NPC data, a one way ANOVA was used to compare the NPC: neutral, left torsion, right torsion, average torsion, left torsion difference, right torsion difference and average torsion difference values between the control and INP groups.

A two way mixed, absolute, single measures ICC was used to determine inter-rater reliability and a one way random effects, single measures ICC was used to assess repeatability of the RAF Rule measure. Spearman's Correlation was used to investigate correlations between the questionnaires and the NPC results, as some of the questionnaire results were not normally distributed. Level of significance was set at $p < 0.05$.

Due to an absence of studies using a RAF Rule to examine convergence in NP patients, the sample size was chosen for each group based on both previous articles measuring NPC using a RAF Rule (Siderov et al., 2001) and those measuring eye movement control in neck pain (Treleaven et al., 2005a; Della Casa et al., 2014).

RESULTS

Forty-two subjects (21 with INP, and 21 healthy controls) were recruited and provided full data. Table 1 shows the sample statistics. There were no significant group differences in age, and no differences in distribution of gender or visual aid use between groups.

The CISS and VSS questionnaires were significantly greater in those with INP compared to controls ($P \leq 0.01$). As expected, the INP group had significantly higher neck pain VAS, NDI and NDI reading scores and higher levels of DHIsf and dizziness VAS compared to healthy subjects.

Table 1

Demographic and questionnaire data comparison (mean, standard deviation or %) between control group and idiopathic neck pain group.

	Control n=21	Neck Pain n=21	P Value
Age (years)	31.62 (14.1)	28.71 (11.3)	0.47
Gender (% females)	76	62	0.51
Use of Visual Aid (%)	28.5	43	0.52
Neck Pain VAS/100mm	1.24 (4)	34.81 (19.5)	<0.01
NDI (%)	1.33 (2.3)	19.43 (7.0)	<0.01
NDI Reading item score /5)	0.1 (0.4)	2.29 (1.7)	<0.01
DHIsf (/13)	12.81(0.5)	11 (2.5)	**0.01**
Dizziness VAS/100mm	0.67 (3.1)	8.91 (18.8)	**0.02**
VSS score (/168)	6.62 (6.1)	21.05 (17.3)	<0.01
CISS score (/60)	8 (7.5)	17.81 (8.7)	<0.01

VAS: Visual Analogue Scale
NDI: Neck Disability Index
DHIsf: Dizziness Handicap Index short form
VSS: Visual Symptom Survey
CISS: Convergence Insufficiency Symptom Survey

There was significantly greater left, right and average torsion differences observed in participants with INP compared to controls.. There were no significant differences for NPC in neutral, average torsion, left torsion, and right torsion (Table 2).

Table 2

Near point convergence break point (NPC) in centimetres (mean and standard deviation) between control group and idiopathic neck pain group.

NPC	Control n=21	Neck Pain n=21	F	p
Neutral	8.4 (2.3)	8.7 (2.2)	.13	0.73
Left Torsion	8.7 (2.4)	9.8 (2.8)	1.8	0.18
Right Torsion	8.6 (2.2)	10.1 (3.4)	2.7	0.11
Average Torsion	8.7 (2.3)	9.9 (3.0)	2.4	0.13
Left Torsion difference	0.3 (1.0)	1.1 (1.1)	7.3	**0.01**
Right Torsion difference	0.2 (0.8)	1.4 (2.1)	6.8	**0.02**
Torsion difference	0.3 (0.8)	1.3 (1.6)	5.9	**0.01**

Average Torsion= (Torsion L +Torsion R)/2,Left Torsion Difference= Torsion L- Neutral, Right Torsion Difference= Torsion R- Neutral, Torsion difference = Average Torsion - Neutral

High interrater reliability, ICC=0.95, 95% confidence interval (CI) (0.89,0.97) and high test-retest reliability, ICC=0.84, 95% CI (0.70 ,0.92) were demonstrated.

There were no significant correlations between NPC measures and the CISS. There were moderate positive correlations present between the torsion difference and both NDI (r=0.43) and dizziness VAS (r=0.42). (Table 3)

Table 3

Correlation data comparison (r value) between questionnaires and Near Point Convergence (NPC) measures.

	CISS	NPC Neutral	NPC Torsion Difference	Neck Pain VAS	NDI (%)	DHIsf (/13)	VSS Score	Dizziness VAS
CISS	1	0.04	0.18	0.58**	0.63**	-0.48**	0.85**	0.34*
NPC in Neutral	0.04	1	0.08	0.08	0.15	-0.06	0.12	-0.001
NPC Torsion Difference	0.18	0.08	1	0.28	0.43**	-0.26	0.20	0.42**

*p<0.05 ** p<0.01
VAS: Visual Analogue Scale
NDI: Neck Disability Index
DHIsf: Dizziness Handicap Index short form
VSS: Visual Symptom Survey
CISS: Convergence Insufficiency Symptom Survey
NPC: Near Point Convergence
Torsion difference= (Torsion L +Torsion R)/2- Neutral

DISCUSSION

Results of this study found abnormal NPC values in INP subjects when their neck was placed in torsion compared to the neutral position but not in the neutral or the torsioned position. This supports the theory of cervical afferent disturbance influencing eye movement in those with INP. Further, the RAF Rule was found to be reliable between testers as well as repeatable and supports its use to measure NPC in the population studied. No significant correlation was observed between the CISS and NPC scores which suggests that CISS cannot be used to screen for CI in this population.

Both the control and INP group had a mean NPC in neutral of 8.4 cm and 8.6 cm respectively. This is aligned with values obtained previously using the RAF Rule in a similar age group to the current study (Adler et al., 2007). However, these values are higher than the previously suggested cut-off of 5cm for NPC break point in healthy adults aged 20-30 years (Scheiman et al., 2003). This may be due to target type, with a fingertip or pencil giving statistically lower NPC break point values than the RAF Rule (Siderov et al., 2001) as used in the current study which uses a distinct thin line. Larger NPC values have also been obtained when targets are moved on a carrier rod such as the RAF Rule, instead of in free space (Adler et al., 2007).

The significant results found for torsion difference are suggestive of abnormal cervical afferent input influencing sensorimotor control such as that observed previously in neck pain (Treleaven et al., 2005b; Yu et al., 2011; Chen et al., 2013; Della Casa et al., 2014). Similarly, results depicting changes seen only when the difference between neutral and torsion positions were compared, have been observed in tests of cervical joint position sense and smooth pursuit in INP (Treleaven et al., 2011b; Chen et al., 2013). Nevertheless, people with WAD have previously shown abnormal NPC values in neutral (Burke et al., 1992),. This

may be due to greater cervical afferent disturbance secondary to trauma, compared to INP patients (Treleaven et al., 2011a). This point is further supported by the significant mild to moderate correlation between both neck pain and disability (r=.43) and dizziness intensity (r=.42) and the NPC torsion difference seen in the current study.

Results indicate the testing used was reliable and repeatable, although the 95% CI for the test-retest data was considerably wide. This is likely due to changes in the participant rather than the examiner measurement method and the small sample size for the reliability studies. ICC values obtained for repeatability and reliability support the use of a RAF Rule to measure NPC in this population.

As NPC scores obtained on the RAF Rule did not correlate with the CISS, this suggests that the CISS could not be used as a substitute for NPC measures in this group. This finding adds to the debate in the literature as to the suitability of self-reported scales such as the Convergence Insufficiency Symptom Survey (CISS) to identify those with CI (Rouse et al., 2004). A possible reason there was no correlation between the survey and RAF Rule values in this cohort could be due to NP patients already experiencing a vast majority of visual symptoms present on the CISS. This may be due to subjects having other potential eye movement control abnormalities such as altered smooth pursuit eye movement and not necessarily CI. This is further supported by the high correlation (r=0.85) between the convergence insufficiency questionnaire (CISS) and the visual symptoms score (VSS) seen in the current study (Table 3). There is considerable overlap between the questionnaires with commonly reported visual symptoms in those with neck pain, such as needing to concentrate to read and visual fatigue present in both questionnaires (Treleaven et al., 2014). Therefore, these questions used in the CISS may not be specific to CI in those with neck pain.

This study has some limitations, with the first being the average age in both groups was about 30 years due to several potential older volunteers with multifocal lenses being excluded; thus negatively affecting the generalisability of this study to older subjects with neck pain. Response bias from subjective reports of diplopia may have been a limitation. However, differences in NPC torsion compared to neutral between groups were still demonstrated. The presence of a possible learning effect was the third limitation with subjects potentially reporting diplopia from the same locations on the RAF Rule with all trials being completed in a row. Previous research has shown that anticipatory convergence movements influenced by working memory, occur if the target moves in a predictable fashion (Kumar et al., 2002) such as in the RAF Rule procedure. However if this were the case it would be expected that torsion would have a better rather than worse response compared to neutral due to the learning effect. A possible tester bias was the fourth limitation as there was no blinding, with potential for clinicians to subconsciously move the target at a varying speed depending on values expected. However, if this greatly influenced the data, differences between the groups in regards to NPC in neutral may have been expected and inter-rater reliability would not have been as high.

Whilst other studies have indicated oculomotor disturbance in NP (Treleaven et al., 2005a; Treleaven et al., 2011c), NPC has not previously been examined in subjects with INP. This study adds to the evidence of oculomotor disturbances including eye movements in the same direction as well as opposite directions in neck pain. The results of the test-retest and inter-rater reliability of the RAF Rule suggest that this is a suitable clinical tool that can be used by physiotherapists to assess NPC. This study also adds to knowledge regarding the use of the CISS as a screening tool for CI in neck pain.

Future studies should consider including subjects with varying levels of pain-related

disability (with/without dizziness) following whiplash and other head/neck traumas (e.g. concussion) to explore if having a traumatic cause of NP demonstrates significantly altered NPC values in neutral and torsion compared to INP patients. There is also potential for the test to be used in those with a primary diagnosis of concussion who often have deficits in NPC (Mucha et al., 2014; Pearce et al., 2015).Altered NPC in torsion may help to identify associated neck trauma as a potential cause of these symptoms psot concussion and the specific methodology used in the current study is currently underway to help to identify any cervical component of NPC disturbances in those post concussion. Further analysis can be done to ascertain the minimal clinically important difference and the minimal detectable change of the RAF Rule for evaluation of CI treatment effectiveness in neck pain. Finally, an investigation appraising the use of the CISS and RAF Rule in older populations and those with corrective devices such as multi-focals, is needed to create sensitive measures in this demographic that may present with neck pain.

CONCLUSION

Results of this study determined there were deficits in NPC in torsion compared to a neutral position in those with idiopathic neck pain likely due to abnormal cervical afferent input. The RAF Rule measure was found to have high interrater reliability and repeatability. .There was no correlation observed between the NPC measures and the CISS, suggesting this survey cannot be used as a substitute for objective measurements of CI. Several directions for future research are suggested including examining traumatic neck pain patients, subjects who wear multi-focals and subjects post concussion and calculating the minimal clinically important difference and the minimal detectable change of the measure.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflicts of interest: none

References

Adler, P, Cregg, M, Viollier, A, Margaret, W. Influence of target type and RAF rule on the measurement of near point of convergence. . Ophthalmic Physiol Opt. 2007; 27: 22-30.

Burke, JP, Orton, HP, West, J, Strachan, IM, Hockey, MS, Ferguson, DG. Whiplash and Its Effect on the Visual-System. Graefes Archive for Clinical and Experimental Ophthalmology 1992; 230(4): 335-339.

Chen, X, Treleaven, J. The effect of neck torsion on joint position error in subjects with chronic neck pain. Manual Therapy 2013; 18(6): 562-567.

Corneil, BD, Olivier, E, Munoz, DP. Neck muscle responses to stimulation of monkey superior colliculus. I. Topography and manipulation of stimulation parameters. Journal of Neurophysiology 2002; 88(4): 1980-1999.

de Vries, J, Ischebeck, BK, Voogt, LP, Janssen, M, Frens, MA, Kleinrensink, GJ, van der Geest, JN. The Cervico-Ocular Reflex Is Increased In People With Non-Specific Neck Pain. Physical Therapy 2016.

Della Casa, E, Helbling, JA, Meichtry, A, Luomajoki, H, Kool, J. Head-Eye movement control tests in patients with chronic neck pain; Inter-observer reliability and discriminative validity. BMC Musculoskeletal Disorders 2014; 15.

Guzman, J, Hurwitz, EL, Carroll, LJ, Haldeman, S, Côté, P, Carragee, EJ, Peloso, PM, van der Velde, G, Holm, LW, Hogg-Johnson, S, Nordin, M, Cassidy, JD, Disorders., BaJD-TFoNPaIA. A new conceptual model of neck pain: linking onset, course, and care: the Bone and Joint Decade 2000-2010 Task Force on Neck Pain and Its Associated Disorders. Spine (Phila Pa 1976) 2008; 33(4 Suppl): 14-23.

Heikkila, HV, Wenngren, B-I. Cervicocephalic kinesthetic sensibility, active range of cervical motion, and oculomotor function in patients with whiplash injury. Archives of Physical Medicine and Rehabilitation 1998; 79(9): 1089.

Kristjansson, E, Treleaven, J. Sensorimotor Function and Dizziness in Neck Pain: Implications for Assessment and Management. Journal of Orthopaedic and Sports Physical Therapy 2009; 39(5): 364-377.

Kumar, A, Han, Y, Garbutt, S, RJ., L. Properties of Anticipatory Vergence Responses. . Invest Ophthalmol Vis Sci. 2002; 43: 2626-32.

McGregor, M. Convergence insufficiency and vision therapy.
. Pediatr Clin North Am. 2014; 61: 621-30.

Montfoort, I, Kelders, WPA, van der Geest, JN, Schipper, IB, Feenstra, L, de Zeeuw, CI, Frens, MA. Interaction between ocular stabilization reflexes in patients with whiplash injury. Investigative Ophthalmology and Visual Science 2006; 47(7): 2881-2884.

Mosimann, UP, Muri, RM, Felblinger, J, Radanov, BP. Saccadic eye movement disturbances in whiplash patients with persistent complaints. Brain 2000; 123: 828-835.

Mucha, A, Collins, MW, Elbin, RJ, Furman, JM, Troutman-Enseki, C, DeWolf, RM, Marchetti, G, Kontos, AP. A Brief Vestibular/Ocular Motor Screening (VOMS) Assessment to Evaluate Concussions Preliminary Findings. American Journal of Sports Medicine 2014; 42(10): 2479-2486.

Pearce, KL, Sufrinko, A, Lau, BC, Henry, L, Collins, MW, Kontos, AP. Near Point of Convergence After a Sport-Related Concussion: Measurement Reliability and Relationship to Neurocognitive Impairment and Symptoms. American Journal of Sports Medicine 2015; 43(12): 3055-3061.

Peterson, B, Goldberg, J, Bilotto, G, Fuller, JH. Cervicocollic reflex: Its dynamic properties and interaction with vestibular reflexes. Journal of Neurophysiology 1985; 54(1): 90-108.

Rouse, M, Borsting, E, Mitchell, L, Scheiman, M, Cotter, S, Cooper, J. Validity and reliability of the revised convergence insufficiency symptom survey in adults. . Ophthalmic Physiol Op 2004; 24: 384-90.

Scheiman, M, Gallaway, M, , F, KA., Peters, R, Hatch, S, M., C. Nearpoint of Convergence; Test Procedure, Target Selection, and Normative Data. . Optom Vis Sci. 2003; 80: 213-25.

Siderov, J, Chiu, S, Waugh, S. Difference in the nearpoint of convergence with target type. . Ophthalmic Physiol Opt. 2001; 1(21): 356-60.

Tesio, L, Alpini, D, Cesarani, A, Perucca, M. Short form of the dizziness handicap inventory. American Journal of Physical Medicine and Rehabilitation 1999; 78(3): 233-241.

Tjell, C, Rosenhall, U. Smooth pursuit neck torsion test: A specific test for cervical dizziness. American Journal of Otology 1998; 19(1): 76-81.

Treleaven, J. Sensorimotor disturbances in neck disorders affecting postural stability, head and eye movement control - Part 2: Case studies. Manual Therapy 2008; 13(3): 266-275.

Treleaven, J, Clamaron-Cheers, C, Jull, G. Does the region of pain influence the presence of sensorimotor disturbances in neck pain disorders? Manual Therapy 2011a; 16(6): 636-640.

Treleaven, J, Clamaron-Cheers, C, Jull, G. Does the region of pain influence the presence of sensorimotor disturbances in neck pain disorders? Manual Therapy 2011b; 16(6): 636-640.

Treleaven, J, Jull, G, Grip, H. Head eye co-ordination and gaze stability in subjects with persistent whiplash associated disorders. Manual Therapy 2011c; 16(3): 252-257.

Treleaven, J, Jull, G, Low Choy, N. Smooth Pursuit Neck Torsion Test In Whiplash Associated Disorders - Relationship To Self Reports Of Neck Pain And Disability, Dizziness And Anxiety. Journal of Rehabilitation Medicine 2005a; 37(4): 219-23.

Treleaven, J, Jull, G, LowChoy, N. Smooth pursuit neck torsion test in whiplash-associated disorders: Relationship to self-reports of neck pain and disability, dizziness and anxiety. Journal of Rehabilitation Medicine 2005b; 37(4): 219-223.

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. Archives of Physical Medicine and Rehabilitation 2008; 89(3): 522-530.

Treleaven, J, Takasaki, H. Characteristics of visual disturbances reported by subjects with neck pain. Manual Therapy 2014; 19(3): 203-207.

Vernon, H. The neck disability index: patient assessment and outcome monitoring in whiplash. Journal of Musculoskeletal Pain 1996; 4: 95-104.

Yu, LJ, Stokell, R, Treleaven, J. The effect of neck torsion on postural stability in subjects with persistent whiplash. Manual Therapy 2011; 16(4): 339-343.

Highlights

- NPC is impaired in neck torsion compared to neutral in INP compared to controls.
- High inter-rater reliability and repeatability of the measure was obtained.
- No correlations were present between the CISS and NPC measures.
- Objective rather than self-reported measures should be used to examine CI in NP.