Musculoskeletal Science and Practice 39 (2019) 45–50

Contents lists available at ScienceDirect

Musculoskeletal Science and Practice

journal homepage: www.elsevier.com/locate/msksp

Original article

Altered trunk head co-ordination in those with persistent neck pain

Julia Treleaven[a,*], Hiro Takasaki[a], Helena Grip[b]

[a] The Neck Pain and Whiplash Research Unit, Division of Physiotherapy, The University of Queensland, Brisbane, 4072, Australia
[b] Dept. of Radiation Sciences, Radiation Physics and Biomedical Engineering, Umeå University, Umeå, Sweden

ARTICLE INFO

Keywords:
Trunk
Head motion
Neck pain
Sensorimotor
Cervico-collic reflex

ABSTRACT

Background: Decreased neck motion and sensorimotor deficits have been identified in those with neck pain. It is thought that these might be related to altered reflex mechanisms between the neck, eyes and the vestibular system. Trunk, head co-ordination might also be altered in neck pain.
Objectives: This study investigated trunk head co-ordination ability in subjects with neck pain compared to asymptomatic controls.
Method: Twenty–four subjects with persistent neck pain and twenty-six age and gender matched healthy controls performed 3 trials of 3 trunk movements whilst trying to keep the head still - (1) alternate trunk movement to the left and right (2) trunk movement to the left (3) trunk movement to the right. Wireless motion sensors positioned over the sternum and the forehead measured trunk and head range and velocity of motion.
Analysis: ANOVA was used to compare trunk and head range and velocity of motion during the 3 tasks.
Results: Neck pain subjects had significantly less trunk movement ($p < 0.05$) and velocity ($p = < 0.02$) as well as significantly increased head movement ($p = < 0.03$) during most tasks compared to control subjects.
Discussion: The results of the study suggest that neck pain subjects have difficulty moving their trunk independently of their head. They are less able to keep the head still while moving the trunk and perform the tasks more slowly. These findings might be related to altered reflex activity of the cervico-collic reflex and sensorimotor control. Further research is required.

1. Introduction

The cervical spine has an important functional role in providing input to the sensorimotor control system along with the visual and vestibular systems and has a high density of afferents as well as specific central and reflex connections to fulfil this role (Treleaven, 2008). Accordingly sensorimotor control disturbances relating to signs of altered head and eye movement control and postural stability and symptoms of dizziness and visual disturbances have been demonstrated in those with cervical disorders. (Kristjansson et al., 2003; Michaelson et al., 2003; Sjöström et al., 2003; Tjell, 1998; Treleaven et al., 2003, 2005; Treleaven and Takasaki, 2014). These features are usually attributed to altered cervical afferent input and subsequent changes to the integration, timing and tuning of sensorimotor control (Treleaven, 2008).

The reflex responses associated with cervical afferents for co-ordinated stability of head and eye movement control include the cervico-ocular reflex (COR) and the cervico-collic reflex (CCR) which are generated by cervical afferents and work in conjunction with other vestibular and visual reflexes. The COR works with the vestibulo-ocular and optokinetic reflexes to control the extra-ocular muscles creating clear vision with head movement (Corneil and Elsley, 2005; Mergner and Rosemeier, 1998) while the CCR works with the vestibulo-collic reflex (VCR) to activate neck muscles to stabilise the head. The CCR is specifically activated during movement in relation to the trunk (Peterson et al., 1985; Peterson, 2004). The VCR and CCR are thought to work together to either stabilise the head in space (VCR) and or with respect to the trunk (CCR) (Reynolds et al., 2008). It is possible that these reflex responses may play a role in altered cervical sensorimotor control in those with neck disorders.

To date most of the work has been related to the COR. For example, increased COR gain in those with neck pain has been identified in a series of studies. (de Vries et al., 2016; Kelders et al., 2005; Montfoort et al., 2008). Interestingly visual and eye movement control disturbances demonstrated in subjects with neck pain (Della Casa et al., 2014; Grip et al., 2009; Treleaven et al., 2011) are thought to reflect disturbances in the interactions involving the COR and central connections between the eyes and the cervical afferents (Mergner et al., 1998) (Tjell and Rosenhall, 1998, Treleaven et al., 2005) Further, deficits in eye head co-ordination demonstrated in those with neck pain

* Corresponding author.
E-mail address: j.treleaven@uq.edu.au (J. Treleaven).

https://doi.org/10.1016/j.msksp.2018.11.010
Received 30 July 2018; Received in revised form 6 November 2018; Accepted 17 November 2018
2468-7812/ Crown Copyright © 2018 Published by Elsevier Ltd. All rights reserved.

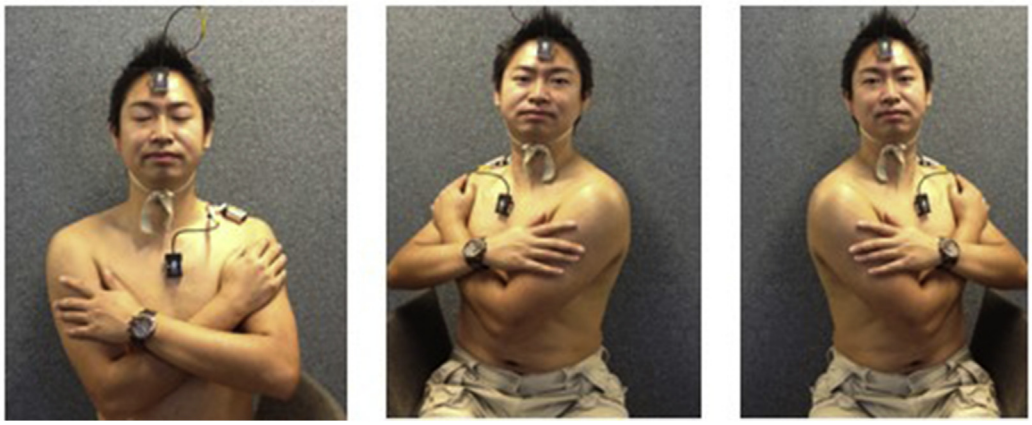

Fig. 1. Trunk head –co-ordination alternating task a) starting position, b) head still rotate trunk right, c) head still rotate trunk left.

may also be due to alterations to the COR and possibly the CCR. (Treleaven et al., 2011) Specifically those with neck pain performed the eye head co-ordination task more slowly, which may indicate difficulty in co-ordinating and performing the task. (Treleaven et al., 2011) In some patients head movement during eye movement was observed. (Grip et al., 2009).

Whilst more attention has been directed towards the COR, some research on the CCR suggests a potential influence of altered CCR control on head on trunk movement control in those with neck pain (Findling et al., 2011; Happee et al., 2017, Reynolds et al., 2008). The CCR is thought to be responsible for maintaining head stability during trunk motion (Reynolds et al., 2008). A change in gain of the CCR reflex, similarly to the COR, may contribute to the inability to maintain head position during trunk movements. (Reynolds et al., 2008) Thus a potential functional deficit of an altered CCR could be altered trunk head movement co-ordination or specifically poorer ability to stabilise the head while moving the trunk.

Thus the aim of this study was to investigate trunk head co-ordination (head still with trunk movement) in those with neck pain compared to asymptomatic control subjects using inertial motion sensors placed on the head and trunk to measure movement kinematics of the head and trunk during the tasks.

2. Materials and methods

2.1. Design

Cross sectional observational study.

2.2. Subjects

Asymptomatic volunteers from university staff and students with no previous history of neck pain, injury or visual problems participated in this study. Subjects with persistent neck pain were also recruited via advertising in print and social media form and from local physiotherapy clinics and those attending an assessment for persistent whiplash in our university clinic. Data from consecutive individuals who met the inclusion criteria were included and data was collected over a 10 month period. All had chronic neck pain of at least three months and up to 5 years duration with a neck disability index (NDI) at least 10% (Vernon and Moir, 1991). They were also required to have at least 45 degrees of active neck and trunk rotation to each side. In addition, subjects were not considered for either group if they had any of the following conditions: previously diagnosed vestibular or inner ear dysfunction and or any associated diseases; diseases of the central nervous system: disorders of the thoracic spine such as fractures, sheuermanns disease or ankylosing spondylitis. Low back or thoracic pain of sufficient level to require current treatment was also an exclusion criteria. Ethical clearance for this study was granted from the Medical Ethics Committee of The XXX and all participants provided informed written consent.

2.3. Self reported measurements

The NDI was administered as part of the screening for inclusion criteria. Once admitted to the study, further questionnaires were administered on the day of the assessment to both asymptomatic and neck pain subjects to collect demographic data, and where relevant aetiology of neck pain and handicap associated with dizziness (Dizziness Handicap Inventory short form –DHIsf) (Tesio et al., 1999). The DHIsf was scored out of a possible 13 where 13 indicated no disability and 0 indicated maximal disability.

2.4. Inertial sensors

Wireless 3D sensors (Inertiacube3, Intersense, Inc., Bedford, MA, USA), an inertial movement analysis system was used to measure trunk and head kinematics. One sensor was placed on a lightweight adjustable headband, centered on the forehead. A second sensor was placed over the sternum using double-sided tape. (Fig. 1). This method using the same sensors on the head has previously been shown to be accurate and reliable to within 3˚. (Treleaven et al., 2011) (Jasiewicz et al., 2007).

2.5. Measurement protocol

Each subject was seated in a chair with a back support with their head in a relaxed neutral position and facing a wall 1 m ahead. The 3D sensors were attached as above and markers were placed on the wall at their eye level, indicating neutral and 30˚ rotation positions to the left and right. Subjects wore their usual optical correction if they were unable to clearly see the markers on the wall.

Each subject was verbally instructed as to when to move the head or trunk and when to return to the starting position for each repetition. The same verbal instruction was given for each patient. There was no instruction with respect to speed with each task. During the trunk movement tasks, the participants sat forward from the back rest and were asked to gently cross their arms across their chest. Participants were asked to move at their own pace within a normal comfortable range of motion. One practice attempt was undertaken for each task to ensure the subject fully understood what was required.

The following 5 head or trunk reference measurements and three trunk head co-ordination movement tasks were performed:

Table 1
Characteristics and comparison of Neck Pain (NP) and Healthy control subjects (mean and standard deviation (SD) unless otherwise stated).

Clinical characteristics	Control (n = 26)	Neck pain (n = 24)	p value
Age (years)	31.6(11)	29(11)	0.28
Neck Disability Index (%)	0 (2)	22.9(15)	0.00
DHIsf/13	12.8(.4)	9.6(3)	0.00
Gender % males	62.5	73%	0.31

2.5.1. Reference measurements

1. *Maximal trunk range of motion (ROM) left and right.* The subject performed three maximal rotations of the trunk in each movement direction (left and right).
2. *Maximal neck range of motion (ROM) left and right.* The subject performed three maximal rotations of the head in each movement direction (left and right).
3. *Reference measurement of 30 degrees trunk range of motion (ROM) left and right.* The subject performed three rotations of the trunk to the markers placed at 30° in each movement direction (left and right).
4. *Reference measurement of 30 degrees neck range of motion (ROM) left and right.* The subject performed three rotations of the head to the markers placed at 30 degrees of head movement in each movement direction (left and right).
5. *Reference measurement of head still.* The subject performed three repetitions of holding the head still without moving the trunk.

2.5.2. Trunk head co-ordination tasks

1. *Left trunk rotation head still.* The subject was instructed to keep the head still and rotate the trunk as far as possible to the left and return to the centre, 3 times
2. *Right trunk rotation head still)* The subject was instructed to keep the head still and rotate the trunk as far as possible to the right and return to the centre, 3 times.
3. *Alternate trunk rotation left and right, head still* The subject was instructed to keep the head still and rotate the trunk as far as possible to the left and then right and return to the centre. This was repeated 3 times.

2.6. Data collection

Data collection at 50 Hz was made with a custom developed LabView program (LabVIEW 6, National Instruments Corp, Austin USA). Data analysis was performed off-line using MATLAB® (The MathWorks Inc., Natick, MA, USA). Data collection and analysis were performed by the examiners (JT and HT), however the data were de-identified prior to analysis, by an independent member of the research team, to ensure the researcher was blinded to the subject group for data analysis and management.

2.7. Data management and statistical analysis

The trunk and head angle data were filtered using a 3rd order Butterworth two-phase low-pass filter with a cutoff frequency of 5 Hz. Head and trunk movement was described in terms of angular rotation and considered axial rotation in the primary plane. Initial position was set to 0° for both the head and trunk prior to each new repetition. Angular velocity was calculated by differentiating the filtered angular trunk and head data. Initiation of head and trunk movement was set to 10% of peak velocity, in consistency with previous studies (Grip et al., 2009; Treleaven et al., 2011). The average of the 3 trials for each variable for each task was used. The peak values in degrees for each repetition of the maximal head and trunk movements in each direction (left and right rotation was taken). Head and trunk range and velocity of motion was computed during each of the 3 trunk movement tasks. Data for left and right sided tasks was also averaged to provide and overall average trunk and head range and velocity during the task trunk rotate head still task.

Data was checked for normality. Differences between the groups for age, NDI and DHIsf scores were assessed using Mann Whitney U tests. Differences between gender was assessed using a Fishers exact test. As there was no significant difference in age or gender distribution between the groups, these factors were not included in the final analysis between groups. ANOVA was used to examine group differences for each of the dependent variables with a bonferroni correction. Glasses delta was calculated to give an effect size of the means difference between the groups for each variable. An alpha level of 0.05 was chosen for all statistical tests. A Spearmans correlation determined any relationships between NDI and DHIsf to the trunk/head measures. SPSS for Windows (Version 25.0, SPSS, Chicago, IL) was used for all statistical analyses.

3. Results

Group characteristics for age, gender, NDI, and DHIsf are presented in Table 1. There were no significant differences between the neck pain and control groups for age or gender. Within the neck pain group 46% had a traumatic incident related to their neck pain while the others had idiopathic neck pain. Preliminary analysis demonstrated no differences between those with and without trauma for all trunk head co-ordination variables despite significantly older age and higher NDI in the traumatic neck pain subgroup and thus this was not considered further in the analysis.

The neck pain group had significantly less trunk range and velocity of motion and increased head movement during most tasks where they were required to keep the head still while moving the trunk. They also had significantly less maximal range of head and trunk motion. Table 2 presents the differences and effect size between groups for the head and trunk movement and velocity variables. Fig. 2 presents an example of the trunk and head movement of a) neck pain participant and b) control performing the trunk rotation 3 times to the left and then 3 times to the right while attempting to keep the head still. Fig. 3 represents the average (left and right) trunk and head range and velocity of movement during the tasks keeping head still while moving the trunk and effect size between groups. There were no significant correlations ($p > 0.05$) between NDI or DHIsf and any of the trunk or head measurements.

4. Discussion

The results of the study indicated that subjects with persistent neck pain were significantly different to control subjects in several elements relating to trunk head co-ordination tasks. Specifically they had less velocity of trunk movement and increased head movement on average during the trunk turning tasks when keeping the head still. No differences were evident in head movement velocity (Table 2 and Fig. 3).

Subjects with neck pain had reduced maximal range of cervical and trunk rotation motion compared to controls and the average trunk range during the trunk rotation head still tasks was similar to the maximal reference trunk position. However, whilst performing the trunk rotation head still tasks, the neck pain subjects moved the trunk more slowly than the control subjects. Subjects were not instructed to move at any particular speed and in general, the controls performed the tasks quite quickly (40–55°/s). The neck pain group in contrast moved on average at (30–38°/s) (Table 2). The slower speed of movement during the tasks observed in this group may indicate difficulty in co-ordinating and performing the task and are similar to findings on head and eye movement control tasks in those with neck pain. (Della Casa et al., 2014; Grip et al., 2009; Treleaven et al., 2011) These subjects may deliberately slow their movement in order to try to perform the

Table 2
Comparison of Neck Pain (NP) and Healthy control subjects (mean and standard deviation (SD) unless otherwise stated) for the trunk head co-ordination tasks.

Variable	Task	Control (n = 26)	Neck pain (n = 24)	P value	95% CI for mean difference	effect size d
Trunk ROM	Head still alternate trunk	103.5(17)	91(24)	**0.04**	0.19–24.4	.73
	Head still trunk left	55.4(7)	47.5(14)	**0.03**	1.35–14.3	1.12
	Head still trunk right	54.7(9)	47.8(15)	0.06	-.38–14.1	0.86
Head ROM	Head still alternate trunk	22.3(10)	32.4(19)	**0.03**	−18.8–1.34	1.01
	Head still trunk left	13.7(5)	20.7(14)	**0.03**	−13–0.93	1.4
	Head still trunk right	14.4(5)	21.6(14)	**0.02**	−13.5–0.9	1.44
Trunk Velocity	Head still alternate trunk	40.2(11)	30.8(13)	**0.01**	−16.4–2.4	.85
	Head still trunk left	55.4(27)	37.8(20)	**0.01**	4.14–31.12	.65
	Head still trunk right	51.4(29)	38.4(20)	0.07	−1.2–27.4	.48
Head velocity	Head still alternate trunk	8.1(4)	10.6(8)	0.2	−1.2–6.24	.61
	Head still trunk left	11.9(8)	14.4(13)	0.4	−8.8–3.8	.31
	Head still trunk right	10.7(10)	13.8(12)	0.2	−9.6–3.6	.31
Maximal Head ROM[a]	Head maximal rotation	72.1(7)	64.1(11)	**0.01**	2.43–13.5	1.14
Maximal Trunk ROM[a]	Trunk maximal rotation	55.7(10)	46.5(11)	**0.01**	2.56–15.9	.92

[a] Average values for the left and right are given.

task with accuracy. Nevertheless, despite this, the subjects with neck pain were less able to maintain head stability during the tasks. These subjects moved the head on average (21–33) degrees compared to the controls (14–22°) even though they were instructed to and were concentrating on keeping the head still. The finding that control subjects were also unable to keep the head reasonably still is interesting. This task required the participants to perform without visual feedback, which may have made it difficult for all participants. Future research should consider whether providing visual feedback leads to a better performance for either group.

Overall the findings suggest impairment in trunk head co-ordination in those with neck pain compared to controls. The 95% CI values of the mean difference between groups for significantly different measures (Table 2 and Fig. 3) were generally larger than measurement errors for this equipment (Jasiewicz et al., 2007) and the effect sizes between groups were moderate to large. Combined this suggests that the results are clinically relevant. Suggested causes for similar findings for eye head co-ordination is altered cervical reflex activity(Tjell and Rosenhall, 1998). Thus it is possible that the changes observed in this current study might be due to a change in the CCR gain (Peterson et al., 1985) and the interaction between the VCR and CCR to either stabilise the head in space and or with respect to the trunk. (Reynolds et al., 2008) A change in gain of either reflex may contribute to the inability to maintain head position during trunk movements. (Reynolds et al., 2008) Alternatively it has been suggested that this could represents a type of strategy employed to produce head locked to trunk movements rather than head on trunk movements to help maintain gaze. (Findling et al., 2011) Further research is required to explore these hypotheses, although the difficulty in isolating the effects of the VCR and CCR are acknowledged (Goldberg and Cullen, 2011).

Nevertheless despite the lack of knowledge of precise mechanisms it would appear that clinical assessment of trunk head co-ordination might be an important component of cervical sensorimotor control assessment and exercises directed towards improving any abnormal head and trunk movement control may be useful in management. Further, since this test utilises trunk on head movement it has promise for a suitable measure to help differentiate cervical sensorimotor deficits from other causes, in a similar way that the neck torsion test has been used for eye movement and postural control (Daley et al., 2018; Williams et al., 2017). Further research is required to explore the mechanisms behind these deficits and the psychometric properties of this test including reliability, the nature of changes over time and the tests' ability to measure any change in response to rehabilitation. Research towards valid clinical methods for assessment of trunk head co-ordination without the need for specific technology and software would also be important.

There are some limitations to the study. Firstly the neck pain group consisted of those with both traumatic and non-traumatic neck pain and

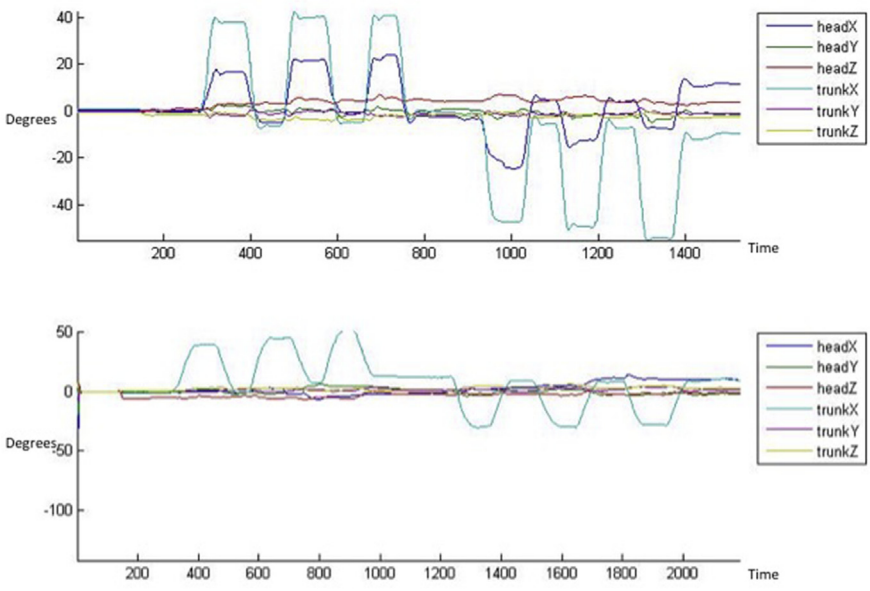

Fig. 2. Example of subjects' performing three trunk rotations (trunk x axis) to the left followed by 3 trunk rotations to the right while attempting to keep the head still. The top is an example of a neck pain subject where there is greater head rotation movement (head x axis) during the task compared to the bottom graph that shows a control subject keeping the head relatively still during the trunk movement.

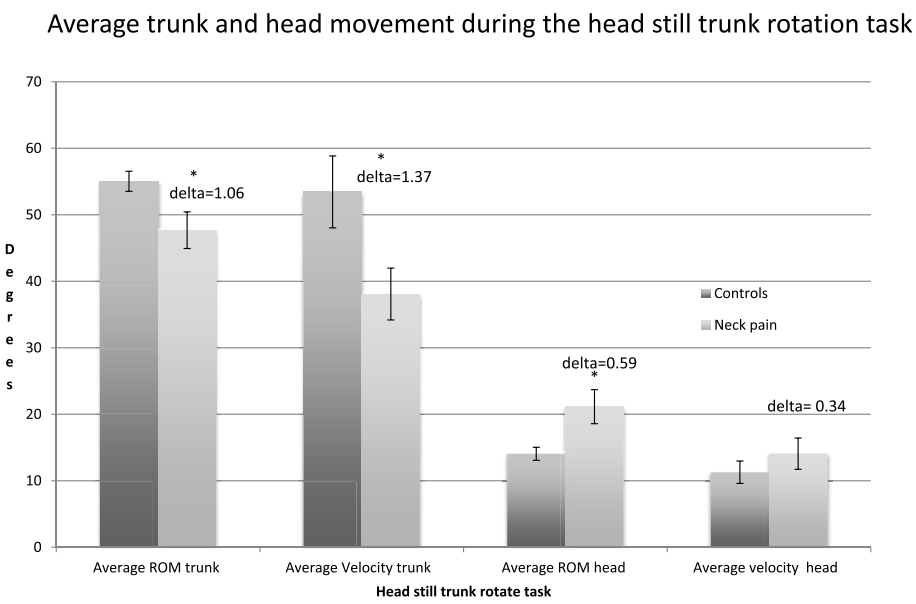

Fig. 3. Comparison of average (left and right) trunk and head range of motion and velocity during the trunk rotation head still task between neck pain and control subjects. (* = $p < 0.05$) Means and standard error presented, delta value represents the effect size of the difference between the groups.

may not be a homogenous group.

Sample size for the subgroups was small and didn't warrant direct comparison. Nevertheless for the purposes of this study, preliminary analysis did not demonstrate differences between these subgroups on any of the trunk head co-ordination task measures. Further there was no significant relationship found between levels of neck pain and disability and these measures, suggesting that the mechanism of neck pain may not be a factor but more research is required in a larger cohort.

It could also be argued that other potential causes such as current pain level during the task as well fear of movement could have influenced the results. However, all neck pain subjects had the available range of motion in the trunk and neck and could perform the individual components of the movements (ie head movement and trunk movement) and no significant correlations were seen between neck pain and disability or the degree of dizziness handicap and any of the trunk or head measures. Despite this the neck pain subjects found it difficult to keep the head still while moving the trunk.

Future research could explore the effects of current pain and other variables on the tasks in a larger cohort.

5. Conclusion

Subjects with persistent neck pain displayed poorer ability to perform a trunk movement task while keeping the head still. Specifically they had less speed of trunk movement and moved the head significantly more during the task despite instructions to keep the head still. This suggests that disturbances are present in trunk head co-ordination which may be related to altered reflex activity and may decrease the ability to stabilise the head during trunk or body movements. Overall, these deficits are likely due to altered cervical afferent input to the sensorimotor control system. Future research is required to explore this further.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.msksp.2018.11.010.

References

Corneil, B.D., Elsley, J.K., 2005. Countermanding eye-head gaze shifts in humans: marching orders are delivered to the head first. J. Neurophysiol. 94, 883–895.
Daley, L., Giffard, P., Thomas, L.C., Treleaven, J., 2018. Validity of clinical measures of smooth pursuit eye movement control in patients with idiopathic neck pain. Musculoskelet. Sci. Pract. 33, 18–23.
de Vries, J., Ischebeck, B.K., Voogt, L.P., Janssen, M., Frens, M.A., Kleinrensink, G.J., et al., 2016. Cervico-ocular reflex is increased in people with nonspecific neck pain. Phys. Ther. 96, 1190–1195.
Della Casa, E., Helbling, J.A., Meichtry, A., Luomajoki, H., Kool, J., 2014. Head-Eye movement control tests in patients with chronic neck pain; Inter-observer reliability and discriminative validity. BMC Muscoskel. Disord. 15.
Findling, O., Schuster, C., Sellner, J., Ettlin, T., Allum, J.H.J., 2011. Trunk sway in patients with and without, mild traumatic brain injury after whiplash injury. Gait Posture 34, 473–478.
Goldberg, J.M., Cullen, K.E., 2011. Vestibular control of the head: possible functions of the vestibulocollic reflex. Exp. Brain Res. 210, 331–345.
Grip, H., Jull, G., Treleaven, J., 2009. Head eye co-ordination and gaze stability using simultaneous measurement of eye in head and head in space movements -potential for use in subjects with a whiplash injury. J. Clin. Monit. Comput. 23, 31–40.
Happee, R., de Bruijn, E., Forbes, P.A., van der Helm, F.C.T., 2017. Dynamic head-neck stabilization and modulation with perturbation bandwidth investigated using a multisegment neuromuscular model. J. Biomech. 58, 203–211.
Jasiewicz, J.M., Treleaven, J., Condie, P., Jull, G., 2007. Wireless orientation sensors: their suitability to measure head movement for neck pain assessment. Man. Ther. 12, 380–385.
Kelders, W.P.A., Kleinrensink, G.J., Van der Geest, J.N., Schipper, I.B., Feenstra, L., De Zeeuw, C.I., et al., 2005. The cervico-ocular reflex is increased in whiplash injury patients. J. Neurotrauma 22, 133–137.
Kristjansson, E., Dall'Alba, P., Jull, G., 2003. A study of five cervicocephalic relocation tests in three different subject groups. Clin. Rehabil. 17, 768–774.
Mergner, T., Rosemeier, T., 1998. Interaction of vestibular, somatosensory and visual signals for postural control and motion perception under terrestrial and microgravity conditions - a conceptual model. Brain Res. Rev. 28, 118–135.
Mergner, T., Schweigart, G., Botti, F., Lehmann, A., 1998. Eye movements evoked by proprioceptive stimulation along the body axis in humans. Exp. Brain Res. 120, 450–460.
Michaelson, P., Michaelson, M., Jaric, S., Latash, M.L., Sjolander, P., Djupsjobacka, M., 2003. Vertical posture and head stability in patients with chronic neck. J. Rehabil. Med. 35, 229–235.
Montfoort, I., Van der Geest, J.N., Slijper, H.P., De Zeeuw, C.I., Frens, M.A., 2008. Adaptation of the cervico- and vestibulo-ocular reflex in whiplash injury patients. J. Neurotrauma 25, 687–693.
Peterson, B., Goldberg, J., Bilotto, G., Fuller, J.H., 1985. Cervicocollic reflex: its dynamic properties and interaction with vestibular reflexes. J. Neurophysiol. 54, 90–108.
Peterson, B.W., 2004. Current Approaches and Future Directions to Understanding Control of Head Movement. Brain Mechanisms for the Integration of Posture and Movement. pp. 369–381.
Reynolds, J.S., Blum, D., Gdowski, G.T., 2008. Reweighting sensory signals to maintain head stability: adaptive properties of the cervicocollic reflex. J. Neurophysiol. 99, 3123–3135.
Sjöström, H.J., Allum, J., Carpenter, M.G., Adkin, A.L., Honegger, F., Ettlin, T., 2003. Trunk sway measures of postural stability during clinical balance tests in patients with chronic whiplash injury symptoms. Spine 28, 1725–1734.
Tesio, L., Alpini, D., Cesarani, A., Perucca, M., 1999. Short form of the dizziness handicap

inventory. Am. J. Phys. Med. Rehab. 78, 233–241.
Tjell, C., 1998. Diagnostic Considerations in Whiplash Associated Disorders. Skovde. .
Tjell, C., Rosenhall, U., 1998. Smooth pursuit neck torsion test: a specific test for cervical dizziness. Am. J. Otol. 19, 76–81.
Treleaven, J., 2008. Sensorimotor disturbances in neck disorders affecting postural stability, head and eye movement control. Man. Ther. 13, 2–11.
Treleaven, J., Jull, G., Grip, H., 2011. Head eye co-ordination and gaze stability in subjects with persistent whiplash associated disorders. Man. Ther. 16, 252–257.
Treleaven, J., Jull, G., Low Choy, N., 2005. Smooth pursuit neck torsion test in whiplash associated disorders - relationship to self reports of neck pain and disability, dizziness and anxiety. J. Rehabil. Med. 37, 219–223.
Treleaven, J., Jull, G., Sterling, M., 2003. Dizziness and unsteadiness following whiplash injury: characteristic features and relationship with cervical joint position error. J. Rehabil. Med. 35, 36–43.
Treleaven, J., Takasaki, H., 2014. Characteristics of visual disturbances reported by subjects with neck pain. Man. Ther. 19, 203–207.
Vernon, H., Moir, S., 1991. The neck disability index : a study of reliability and validity. J. Manip. Physiol. Ther. 14, 409–415.
Williams, K., Tarmizi, A., Treleaven, J., 2017. Use of neck torsion as a specific test of neck related postural instability. Musculoskelet. Sci. Pract. 29, 115–119.