Retraining Cervical Joint Position Sense: The Effect of Two Exercise Regimes

Gwendolen Jull, Deborah Falla, Julia Treleaven, Paul Hodges, Bill Vicenzino

Division of Physiotherapy, The University of Queensland, Brisbane, QLD, 4072, Australia

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ABSTRACT: This study compared the effects of conventional proprioceptive training and craniocervical flexion (C-CF) training on cervical joint position error (JPE) in people with persistent neck pain. The aim was to evaluate whether proprioceptive training was superior in improving proprioceptive acuity compared to another form of exercise, which has been shown to be effective in reducing neck pain. This may help to differentiate the mechanisms of effect of such interventions. Sixty-four female subjects with persistent neck pain and deficits in JPE were randomized into two exercise groups: proprioceptive training or C-CF training. Exercise regimes were conducted over a 6-week period, and all patients received personal instruction by an experienced physiotherapist once per week. A significant pre- to postintervention decrease in JPE, neck pain intensity, and perceived disability was identified for both the proprioceptive training group ($p < 0.001$) and the C-CF training group ($p < 0.05$). Patients who participated in the proprioceptive training demonstrated a greater reduction in JPE from right rotation compared to the C-CF training group ($p < 0.05$). No other significant differences were observed between the two groups. The results demonstrated that both proprioceptive training and C-CF training have a demonstrable benefit on impaired cervical JPE in people with neck pain, with marginally more benefit gained from proprioceptive training. The results suggest that improved proprioceptive acuity following intervention with either exercise protocol may occur through an improved quality of cervical afferent input or by addressing input through direct training of relocation sense. © 2006 Orthopaedic Research Society. Published by Wiley Periodicals, Inc. J Orthop Res 25:404–412, 2007

Keywords: neck pain; proprioception; exercise; cervical joint position error

INTRODUCTION

Impairments have been identified in cervical muscle and somatosensory function in patients with neck pain. Deficits have been identified in cervical range of motion,[1] muscle function,[2] and, of interest in this instance, the postural control system. With regard to the postural control system, people with neck pain have demonstrated altered proprioception (tested by cervical joint position sense),[3,4] balance disturbances,[5,6] altered eye movement control,[7,8] and altered postural activity of cervical muscles.[9]

Abnormal joint position error (JPE) has been detected in patients with neck pain using either tests of ability to relocate the natural head posture after an active movement or to actively relocate a position within a movement plane.[3,4,10] These disturbances to postural control have been attributed to altered input from cervical afferents.[11] There is an abundance of receptors in the cervical muscles,[12,13] and there are multiple cervical central and reflex connections to the vestibular, visual, and postural control systems.[14,15] In particular, the deep portions of the suboccipital muscles have the highest cervical receptor density[12,13] and are known to have a specific role in these reflex and central connections.[13,16,17]

Exercise programs tailored to rehabilitate cervical proprioception have been shown to improve joint position error[18,19] as well as a decrease in neck pain with these specific interventions. There was no significant change in JPE in the control groups. Such programs include gaze stability exercises, eye–head coordination and/or practice of relocation of the head on the trunk.[18,19] These specific proprioceptive training regimes are designed to target the deep suboccipital muscles and reflex connections. The issue raised is whether such training regimes induce greater improvements in proprioceptive acuity (measured as a reduction in joint reposition error) compared to other forms of

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Correspondence to: Gwendolyn Jull (Telephone: +61-7-3365 2275; Fax: +61-7-3365-2775; E-mail: g.jull@ug.edu.au)

exercise, which have also been shown to reduce neck pain.[20]

The purpose of this study was to compare a conventional proprioceptive training program based on that described by Revel[19] to a second exercise intervention, which trains the coordination of the neck flexor muscles, and in particular, the deep cervical flexor muscles (longus capitis and colli) with a craniocervical flexion (C-CF) exercise.[20,21] The proposed mechanism by which this latter exercise approach contributes to pain relief is reasoned to be through improvement of the contractile capacity of the deep cervical flexor muscles for their role in supporting the cervical lordosis and cervical segments[22] as well as improvement of the coordination between the superficial and deep layers of the neck flexor muscles.[21] Enhanced neck proprioception has not been considered to contribute in a major way to the efficacy of this approach, as the exercise program does not directly address the deep suboccipital extensor muscles or directly comply with guidelines for proprioceptive training programs that have demonstrated improvements in cervical JPE.[18,19] It was anticipated that the results of this study might help to differentiate the physiological mechanisms of effect of programs that train proprioception and coordination of cervical muscles.

MATERIALS AND METHODS

Subjects

Sixty-four female subjects with a history of chronic neck pain of either idiopathic ($n = 39$) or traumatic ($n = 25$) origin of greater than 3 months' duration with abnormal measures of joint position sense participated in this study. Sample size was based on the difference in joint position error in neck rotation between groups of chronic neck pain and asymptomatic subjects.[4] With a 2° (80%) difference, at 80% power, 95% confidence, and a standard deviation of 2.7°, 58 subjects were required. An allowance was made for a 10% drop out rate, increasing the sample size to 64.

Subjects were recruited by advertisements in the local press. For entry to the study, patients had to have a JPE that fell outside the upper 95% confidence interval of normative data, greater than 3.0° following left rotation, 3.6° rotation to the right, and 3.2° following an extension movement.[4] A JPE deficit had to be present in two out of the three directions (left rotation, right rotation, extension). Those who fulfilled the criteria underwent a clinical examination of the cervical spine to confirm the presence of cervical spine dysfunction.[23] Subjects were excluded if they had undergone cervical spine surgery, presented with any neurological signs, or had participated in a neck exercise program in the past 12 months.

Ethical approval for the study was granted by the Institutional Medical Research Ethics Committee, and all procedures were conducted according to the Declaration of Helsinki. Written informed consent was provided before participation.

Exercise Interventions

Patients with chronic neck pain were randomized into two exercise groups: proprioceptive training and C-CF training. Randomization was conducted by an independent researcher using computer-generated random numbers. Exercise regimes were conducted over a 6-week period, and patients in each group received personal instruction and supervision by an experienced physiotherapist once per week for the duration of the trial. None of the exercise sessions were longer than 30 min. Subjects were asked not to receive any other form of specific intervention for their neck; however, any usual medication was not withheld from any participant. All subjects were supplied with an exercise diary and requested to practice their respective regime twice per day for the duration of the trial. The exercise session occupied a period of no longer than 10–20 min per day. The exercises were to be performed without any provocation of neck pain.

Proprioceptive Training

Patients trained cervical proprioception using a regime based on that described by Revel and colleagues.[19] Exercises included head relocation practice, gaze stability, eye-follow and eye/head coordination exercises. Relocation practice involved the practice of relocating the head back to the natural head posture and to predetermined positions in range, first with eyes open using feedback from a laser attached to their head and then with eyes closed.[19] All active movements of the cervical spine (flexion, extension, rotation, and lateral flexion) were used. Oculomotor exercises were progressed through several stages, commencing with eye movement with the head stationary, progressing to movements of the head with visual fixation on a target.[19] Eye/head coordination exercises commenced with rotation of the eyes and head to the same side, in both left and right directions. Subsequently, the patient practiced leading with the eyes first to a target, followed by the head, ensuring the eyes keep focused on the target. As a further progression, the eyes were moved first, then the head, to look between two targets positioned horizontally or vertically, and finally, the eyes and head were rotated to the opposite side, in both the left and right directions. Exercises were further progressed by increasing the speed and range of movements and/or alteration of the visual target.

Craniocervical Flexion Training

The low load training of the craniocervical flexor muscles followed the protocol described by Jull et al.[21] This exercise targets the deep flexors of the upper cervical region, the longus capitis, and colli, rather than the superficial flexors, sternocleidomastoid, and anterior scalene muscles, which flex the neck but not the head. The patient was instructed to perform and hold progressively inner ranges of C-CF while trying to keep the superficial flexors relaxed. Patients were first taught to perform a slow and controlled C-CF movement. They then trained to be able to statically hold progressively increasing inner ranges of C-CF. Subjects were guided to the increasing inner range positions through visual feedback gained from the dial of an air-filled pressure sensor (Stabilizer^{TM}, Chattanooga Group Inc., Chattanooga, TN) placed behind the neck, which monitors the slight flattening of the lordosis. This flattening has been shown to accompany contraction of longus colli.[22]

Outcome Measures

A series of measures were made at baseline and in the week immediately after treatment (week 7) in line with the aim of the study to better understand the mechanism of effect of the two different exercise approaches. The assessor was blinded to subject group for the outcome assessments.

Joint Position Error

JPE was assessed using the method described by Revel et al.[3] The subject's ability to relocate the natural head posture was tested following active cervical movements into left and right rotation and extension. Movement of the head was measured with the 3-Space Fastrak (Polhemus, Navagation Science Division, Kaiser Aerospace, Vermont). The Fastrak is a noninvasive electromagnetic device that tracks the positions of sensors relative to a source in three dimensions. A sensor was placed on a lightweight adjustable headband centered on the forehead of the subject. Another sensor was placed over the spinous process of the seventh cervical vertebrae using double-sided tape to minimize movement of the sensor relative to the skin. Data consisted of a 3×3 matrix of direction cosines, for the orientation of the forehead sensor relative to the sensor at C7. The difference between the starting position and position on return was calculated in degrees for each of the three movements tested. This difference represented the accuracy (absolute error) with which the subjects could relocate the natural head posture in the primary plane of movement, the JPE. Between-days repeatability of measurement of JPE in the test of relocation to the neutral head posture using this methodology has previously been established in our laboratory.[24]

Measures of Pain and Disability

Patient's perceived pain and disability were monitored before and after the intervention. Patients completed the Neck Disability Index (NDI)[25] (score out of 50) to provide a measure of perceived impairments resulting from their neck pain. Average intensity of neck pain was measured on a 10-cm Numerical Rating Scale (NRS) anchored with "no pain" and "the worst possible pain imaginable."

Measurement Procedure

Subjects were comfortably positioned in sitting with their feet flat on the ground, their head in the natural resting position, and requested to focus on a target that was positioned at eye level. Subjects were familiarized with the task and performed one practice movement in each direction (extension, left rotation, and right rotation). For the formal tests, subjects were blindfolded, and their natural head position was set as zero on the Fastrak. They were asked to perform the test neck movement to the end of their available range and return as accurately as possible to the starting position. Three trials were performed each of left and right neck rotation and extension. Before each subsequent trial in the movement direction, the subject's head was manually repositioned back to the original starting position by the examiner, who was guided by the real-time display on the computer screen in three dimensions. Prior to each new movement direction, the subject was able to recenter their starting position using vision on an adjustable target, before being blindfolded again.

Data Management and Statistical Analysis

JPE was calculated as the mean of the absolute errors for the three trials in each direction (extension, right rotation, and left rotation). Single-sample t-tests were conducted to investigate if there were any baseline differences between the groups in JPE, NDI, and NRS, as well as to investigate any pre- to post-differences within each group. Two-sample t-tests were conducted to compare measures between the groups pre- to post-exercise intervention. Pearson correlation coefficients were calculated to examine the correlation between baseline JPE and change in JPE following intervention for each movement direction and for each intervention group. All statistical analyses were performed using SPSS 10.0 for Windows. A value of $p < 0.05$ was used as an indicator of statistical significance.

RESULTS

Of the 64 subjects recruited for this study, six were lost to follow-up assessment. Subject descriptives are presented in Table 1. Baseline characteristics of JPE in all three directions and of subjects' pain and disability levels were not different between the two intervention groups (all $p > 0.05$). Subject

Table 1. Baseline Characteristics for Patients with Chronic Neck Pain Randomized into a Craniocervical Flexion Exercise Intervention or a Conventional Proprioceptive Training Intervention

	Craniocervical Flexion Exercise Intervention ($n = 30$)	Proprioception Exercise Intervention ($n = 28$)
Age	42.7 ± 10.8	39.0 ± 11.6
Length of neck pain history (years)	8.7 ± 7.1	10.6 ± 9.3
Neck pain intensity (NRS 0–10)	6.3 ± 1.7	6.7 ± 1.5
Neck Disability Index (50)	17.6 ± 4.9	21.6 ± 9.1
JPE		
Rotation (R)	4.9 ± 1.8	5.9 ± 3.4
Rotation (L)	4.6 ± 2.3	5.2 ± 2.6
Extension	5.7 ± 3.2	4.9 ± 3.1

Mean and standard deviations are shown. There were no significant differences in baseline characteristics between intervention groups.

attendance rate was 5.9 ± 0.5 (of 6) sessions and no subject reported receiving any other treatments in the intervention period.

Changes in Cervical Joint Position Error following the Intervention

Figure 1 presents the pre- and post intervention JPE in all directions for both groups. JPE decreased following interventions for both the C-CF training and proprioceptive training groups on return from right rotation ($t_{29} = -2.7, p < 0.05$; $t_{27} = -3.9$, $p < 0.0001$), from left rotation ($t_{29} = -2.9$, $p < 0.01$; $t_{27} = -6.2$, $p < 0.0001$) and from extension ($t_{29} = -3.2$, $p < 0.01$; $t_{27} = -4.8$, $p < 0.0001$). As illustrated in Figure 2, patients who participated in the proprioceptive training demonstrated a greater reduction in JPE from right rotation following the intervention compared to the C-CF training group ($t_{42} = 2.1, p < 0.05$). No significant difference was identified between groups for change in JPE from extension ($t_{49} = -0.1$, $p = 0.9$) and from left rotation ($t_{51} = -1.1, p = 0.3$).

Correlation between Baseline Measures and Change following Intervention

Significant negative correlations were identified between baseline JPE and change in JPE following intervention for each movement direction and for each intervention group (Fig. 3). In all cases, individuals with greater baseline error had greater improvements in JPE. However, Pearson correlation coefficients were consistently higher for the proprioception training group compared to the C-CF training group in each movement direction (Fig. 3).

Measures of Pain and Disability

Both intervention groups demonstrated a significant reduction in average intensity of pain (proprioceptive training -1.9 ± 1.9; C-CF training, -2.8 ± 2.2; both $p < 0.001$), and NDI score (proprioceptive training -8.4 ± 8.3; C-CF training, -6.9 ± 5.3; both $p < 0.001$). There was no significant difference between groups for the changes in reported pain (NRS) ($t_{55} = -1.6, p = 0.1$) and NDI ($t_{45} = 0.8, p = 0.4$).

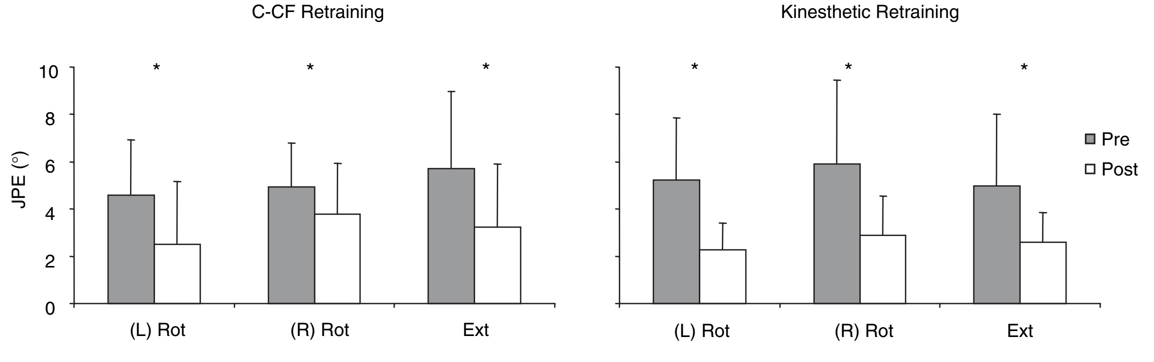


Figure 1. Pre- and post intervention joint position error (JPE) data: Pre- and post intervention joint position error (JPE) data are presented for left (L) and right (R) rotation (ROT) and extension (EXT) for both the craniocervical flexion (C-CF) training group and proprioception training group. *Indicates significant difference between pre and post intervention data ($p < 0.05$).

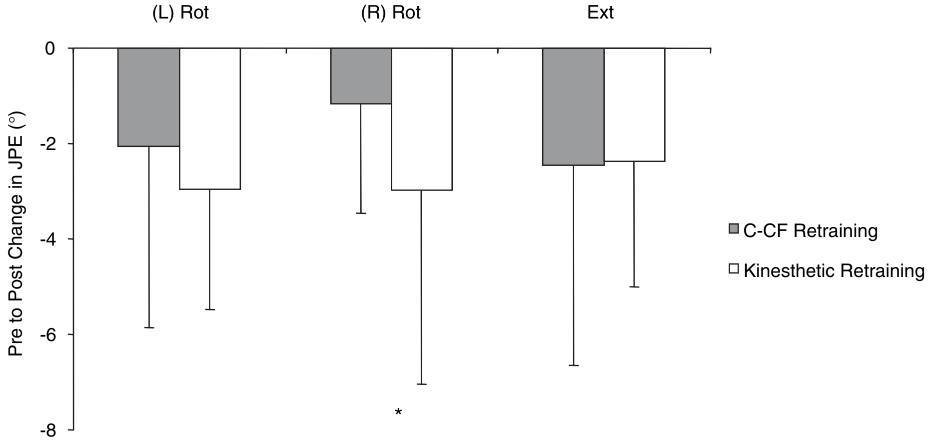


Figure 2. Group comparisons for change in joint position error (JPE) following intervention: comparisons are made between the craniocervical flexion (C-CF) training group and proprioception training group for JPE in left (L) and right (R) rotation (ROT) and extension (EXT). *Indicates significant difference between groups ($p < 0.05$).

DISCUSSION

The results of this study demonstrate that both a conventional proprioceptive training protocol and a program that trains coordination of the craniocervical flexor muscles leads to improvement in JPE after a 6-week training period. The improvement in JPE was similar between the training groups for the directions of rotation from the left and extension. Although both exercise regimes improved JPE in rotation from the right, the more conventional proprioceptive training protocol provided a greater benefit than did C-CF training. In addition, the correlations between baseline JPE and change in JPE following training for all three movement directions were stronger for the proprioceptive training group compared to the C-CF training group.

The result for the C-CF training protocol was somewhat surprising, as this exercise emphasizes

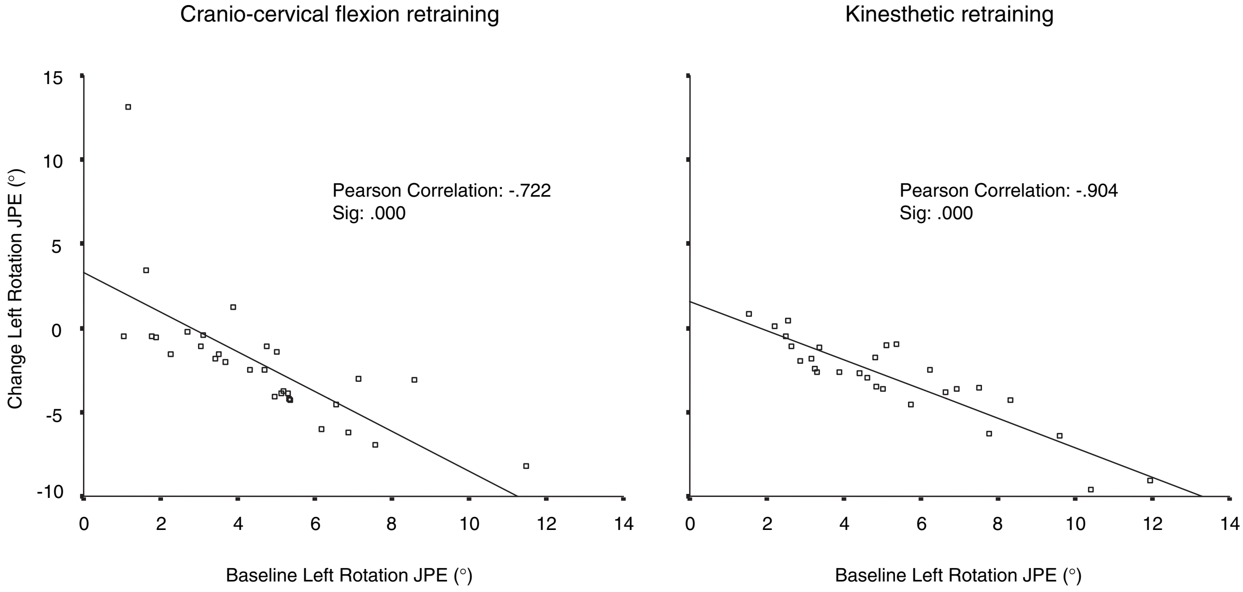
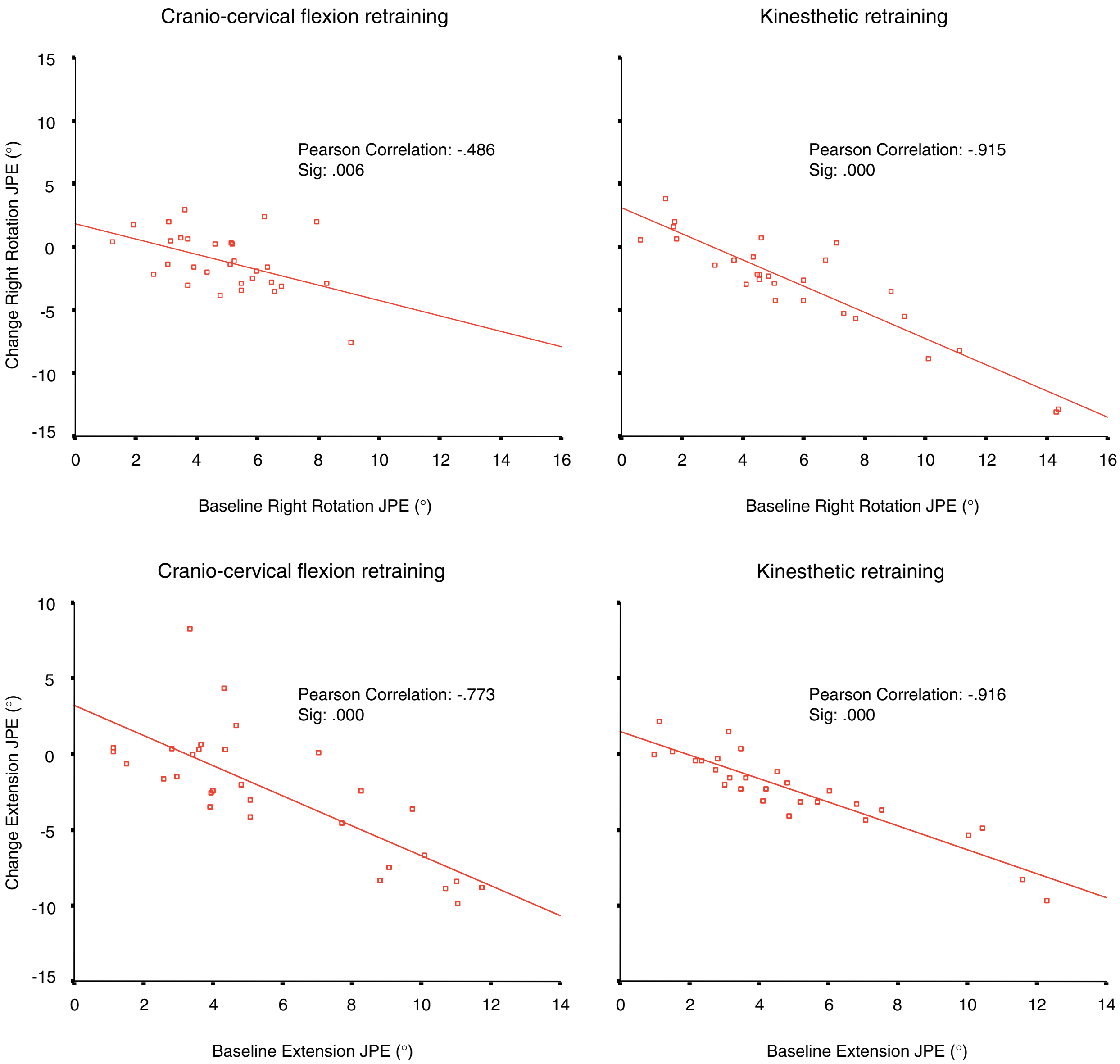


Figure 3. Correlations between baseline joint position error (JPE) and change in JPE following intervention: Pearson correlation coefficients and significance are provided for correlations between baseline JPE and change in JPE following intervention in the directions of left and right rotation and extension for both the craniocervical flexion training group and proprioception training group.


Cranio-cervical flexion retraining

Kinesthetic retraining

Cranio-cervical flexion retraining

Kinesthetic retraining

Figure 3. (*Continued*)

one plane of motion (sagittal plane) and is not designed with a primary aim of reeducating general kinaesthetic sense. Yet this training program was shown to improve cervical proprioception in measures of movement in both the transverse and sagittal planes. Thus, despite being restricted to a single plane, the training led to improvements in a second plane.

Several possible mechanisms may explain the improvements in JPE following C-CF training. First, C-CF training directly activates the deep cervical flexor musculature,[26] which has been shown to have a relatively high density of muscle spindles.[12] Thus, the repeated contractions involved in C-CF training may improve muscle spindle function translating to improved cervical proprioception. Second, the C-CF training program involves repeated and precise targeting of positions within the C-CF range using biofeedback provided by a pressure sensor under the neck as the subject practices precise holding of progressive inner range positions. Positional relocation practice is a component of conventional proprioceptive training protocols,[19] and thus, this repeated targeting of position in the C-CF training could be a fortuitous aspect of this regime. However, how this leads to improvements in the other planes of movement is unclear. Third, it is also possible that improved cervical neuromuscular control gained from C-CF training could decrease stresses placed on the joints and other structures of the cervical region.[22,27,28] It has been suggested that abnormal joint stress may alter firing of cervical afferents with resultant changes in proprioceptive function.[29] Fourth, sternocleidomastoid and scalene muscle activity is reduced and deep muscle activity is increased following C-CF training (G. Jull, unpublished data) and this may alter cervical intersegmental kinematics leading to improved acuity for cervical movement. Proprioceptive acuity has been argued to both increase[30] and decrease[31] with muscle activity. Thus, changes in activity of the deep and superficial muscles may be responsible for changes in proprioception.[31]

Another consideration is the decrease in reported pain and disability following both conventional proprioceptive training and C-CF training, which is in accordance with other studies.[19,20] Pain has been argued to interfere with transmission of afferent input in the dorsal horn, and interfere with processing of input at cortical and subcortical levels.[30,32–35] Other studies directed at pain relief, and not using any form of exercise, have reported improvements in cervical JPE. For example, short-term improvements in cervical JPE were demonstrated following neck manipulation and acupuncture.[36] Heikkila et al.[36] suggested that improvements gained with acupuncture (or indeed neck manipulation) could also have been due to a reduction in any abnormal muscle activity associated with the neck pain. This concurs with the opinion of Fattori et al.,[37] who suggest that the positive effects of acupuncture on the postural control system in those with neck pain are due to either reduced pain or muscle tension via changes in muscle spindle activity. Interestingly, the improvements in JPE with acupuncture and manual therapy were only identified in return from cervical extension and did not influence return from rotation.[36] If improved JPE is explained by the mechanisms outlined above, it is unclear why the improvement is restricted to a single plane of movement in that study. The C-CF training, however, demonstrated improvements in JPE from both rotation and extension, and this suggests that a C-CF training program leads to more generalized improvements in proprioception than either acupuncture or neck manipulation.

Although both C-CF and the conventional proprioceptive training improved joint position sense, there is evidence from this study that marginally more benefit was gained from the conventional proprioceptive training regime: there was a significantly greater improvement in JPE from right rotation with proprioceptive training when compared to C-CF training; and the change in JPE following proprioceptive training was more strongly correlated with baseline JPE than following C-CF training. These findings could either reflect the fact that the relocation practice in the proprioceptive training program directly trained the impairment and the outcome measure of JPE or because the program addressed the cervical afferent input in its functional role by the inclusion of eye movement exercises, noting the close relationship between the deep cervical extensors/rotators and horizontal eye movement.[38,39] Thus, proprioceptive retraining incorporating eye–head coordination may specifically influence the suboccipital cervical receptors and muscles. In juxtaposition to this argument, we identified no direct correlation between measures of neck influenced eye movement control (the smooth pursuit neck torsion test) and cervical JPE in a group of people with whiplash-associated disorders.[40] In the present study, proprioceptive training encompassed both relocation retraining and eye–head coordination.

CONCLUSION

The results of this study indicate that both proprioceptive training and C-CF training are efficacious in improving cervical JPE after a 6-week training period, albeit that there were some marginally greater benefits with the proprioception training protocol. The results imply that there is overlap between the physiological mechanisms of effect of each training regime. A central and common feature might be an improved quality of cervical afferent input into the CNS afforded by exercises that involve repeated specific contractions of craniocervical musculature, which contain high densities of muscle spindles, whether by precise movement relocation practice or eye–head coordination exercises. The alleviation of pain afforded by both exercise regimes may also contribute to the effect by lessening any interference with transmission of afferent input in the dorsal horn or at cortical and subcortical levels. This study has also highlighted further avenues of research, including a need to better understand relationships between suboccipital muscle dysfunction and cervical JPE, and whether the effects gained from proprioceptive training are purely due to the benefit of practice of the JPE task or are more specifically related to visual retraining. It will also be important to determine the long-term benefits of such interventions.

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