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Specificity in Retraining Craniocervical Flexor Muscle Performance

STUDY DESIGN: A multivariate repeated-measures independent-group study design.

OBJECTIVES: To compare the effect of a craniocervical flexion exercise (CCFEx) program to that of a conventional cervical flexion exercise (CFEx) program in training isometric craniocervical flexor muscle performance.

BACKGROUND: The craniocervical flexor muscles are important muscles of the cervical spine, as they have been shown to be impaired in persons with chronic neck pain. While both CCFEx and CFEx protocols have been advocated to train craniocervical flexor muscle performance, at present there is no consensus as to the most effective method.

METHODS AND MEASURES: Fifty females with chronic mild neck pain and disability status were randomly allocated into a 6-week program of either CCFEx (n = 27) or CFEx (n = 23). Isometric dynamometry measurements of craniocervical flexor muscle performance (maximal voluntary contraction, endurance at 50% of maximal voluntary contraction) were recorded before and following the exercise program. Changes in craniocervical flexor muscle performance (pretraining-posttraining) within and between exercise groups were analyzed with analysis of variance models.

RESULTS: Both exercise interventions significantly improved isometric craniocervical flexor muscle performance ($P<.02$). No significant differences in improvement of muscle performance were observed between the 2 exercise interventions.

CONCLUSION: It appears that isometric craniocervical flexor muscle performance can be trained with either a CCFEx protocol or a conventional CFEx protocol in patients with mild neck pain and disability. *J Orthop Sports Phys Ther 2007;37(1):3-9. doi:10.2519/jospt.2007.2237*

KEY WORDS: cervical spine, craniocervical flexion, neck pain, rehabilitation

Neck disorders are a common and costly problem in the community, affecting approximately 70% of people at some point in their life.[6,22] Exercise to improve the performance of the cervical spine muscles has been shown to be an effective means of alleviating chronic neck pain.[16,40] With regard to the cervical flexors, there is mounting evidence of an association between chronic neck pain and impaired craniocervical flexor (CCF) muscle performance.[7,15,28] Craniocervical flexion is the principal action of the deep cervical flexor muscles (longus capitus, longus colli [superior portion], and rectus capitis anterior) that structurally support cervical motion segments.[17,19,35] Hence, CCF muscle training is recommended clinically for the management of neck pain.[3,14]

At present there is no consensus as to the best method of training CCF muscle performance. Jull et al[14] endorse a specific craniocervical flexion exercise (CCFEx) protocol in supine, with the head remaining on the supporting surface, guiding the sustained CCF into a progressively more inner-range muscle contractions with feedback from an inflatable biofeedback device (Stabilizer; Chattanooga Group, Inc, Hixon, TN) placed behind the neck. Alternately, CCF muscle performance may be trained within the cervical flexor synergy, utilizing a conventional cervical flexion exercise (CFEx) (head lift) protocol. As the head is lifted against gravity, the CCF muscles are trained in their capacity to prevent gravity-induced craniocervical extension, as indicated by a forward thrust of the chin.[2,9,37]

Although both craniocervical flexion and cervical flexion movements utilize the CCF muscle group,[27] there are fundamental differences between these exercises. Specifically, craniocervical flexion occurs principally about the upper cervical motion segments,[10,34,38] while cervical flexion, although involving multiple cervical motion segments, can be primarily resolved to motion about the cervicothoracic junction.[10,12] It is evident that these are separate cervical flexor muscle actions, that exert torque primarily about opposite ends of the cervical spine and have been shown to elicit different patterns of cervical flexor muscle activation.[27] Both cervical flexion and craniocervical flexion muscle contraction methods have been shown to elicit similar EMG activation of the deep CCF muscles when tested isometrically over a range of contraction intensities (maximal voluntary contraction [MVC], 20% and 50% of MVC).[27] However, compared to a craniocervical flexion method, cervical flexion additionally elicited substantial activation of superficial cervi-

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cal flexor muscles (sternocleidomastoid, anterior scalene)[27] that do not have a craniocervical flexion function but are required to flex the lower cervical spine upon the thorax as the patient attempts to raise the head off the supporting surface. We propose that the additional recruitment of these superficial muscles during a cervical flexion method lessens the specificity of the method to train CCF muscle performance, compared to a craniocervical flexion method that can be performed with minimal activation of these superficial muscles, particularly when performed at low and moderate intensities of effort (20% and 50% of MVC).[27] This specificity of muscle action may be particularly relevant early in rehabilitation to address the specific impairments observed in these deep CCF muscles during submaximal muscle tests in patients with neck pain.[7,15,28]

To compare the effectiveness of these exercise protocols in improving CCF muscle performance, isometric CCF muscle performance was compared following 6 weeks of CCFEx training and 6 weeks of CFEx training in 2 groups of individuals with mild neck pain and disability. Measurements of isometric CCF muscle performance, including strength (MVC) and endurance at moderate load (50% of MVC), were recorded with a dynamometer[28,30] before and following the exercise programs. We hypothesized that the specificity of the CCFEx protocol to the deep CCF muscles would yield superior CCF muscle performance gains than the CFEx protocol, particularly during the submaximal endurance test, where deep CCF muscles could be trained with minimal contribution by the superficial cervical flexors.

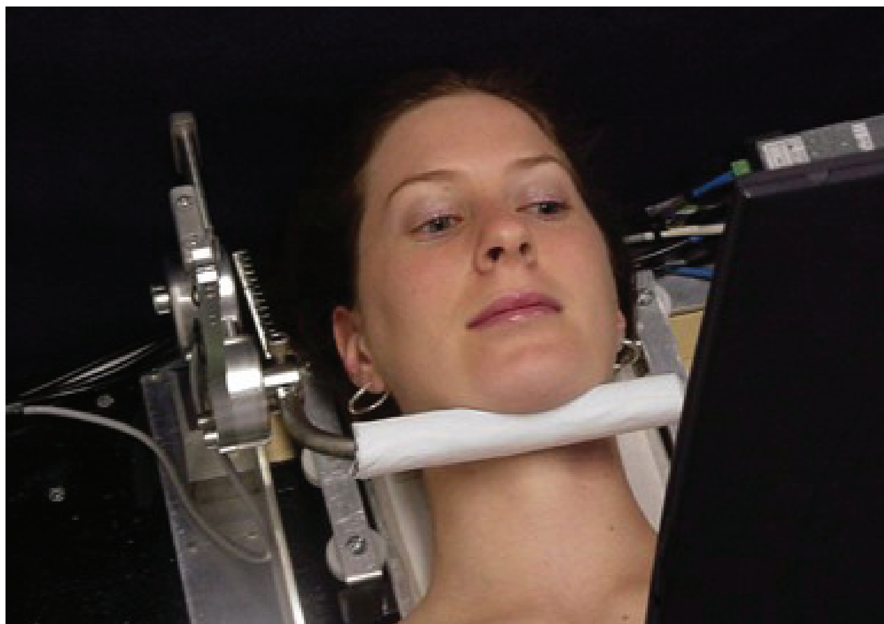

FIGURE 1. Craniocervical flexion dynamometry device for the measurement of isometric craniocervical flexor muscle torque about the axis of rotation (AOR) of the C0-1 motion segment. The dynamometer axis was aligned to the participants' C0-1 AOR landmark (concha of the ear). The application pad of the dynamometer resistance arm is positioned at the undersurface of the mandible. The participants' craniocervical flexion effort resulted in torque at the dynamometer axis that was recorded in Newton-meters (Nm). Visual realtime feedback of performance was provided to the participant on a monitor.

METHODS

Subjects

Fifty female volunteers with chronic neck pain participated in the study. These subjects had consented to participate in a larger clinical trial performed within the research institution (Jull G, Hodges P, Vicenzino B. Clinical Trial: Physiological Mechanisms of Efficiency of Cervical Flexor Muscle Retraining. National Health and Medical Research Council ID 252771) and had been randomly allocated by an external body into either the CCFEx group (n = 27; mean ± SD age, 36.9 ± 9.5 years; mean ± SD body mass, 67.1 ± 14.7 kg; mean ± SD height, 165.7 ± 7.5 cm) or the CFEx group (n = 23; mean ± SD age, 37.9 ± 11.3 years; mean ± SD body mass, 65.8 ± 9.2 kg; mean ± SD height, 166.2 ± 7.2 cm). All participants reported a history of neck pain duration of greater than 3 months, demonstrated positive findings on a physical manual examination of the cervical spine (altered joint motion and painful reactivity to palpation),[13] and demonstrated evidence of CCF muscle impairment based on poor performance on the clinical craniocervical flexion test method (inability to sustain target pressure levels of 24 mmHg or greater for a period of 10 seconds), indicated by the pressure biofeedback device. Only participants determined to have mild neck pain and disability according to a Neck Disability Index rating (participants scores that fell between 10 and 28 points out of a possible 100 points)[36] were included to avoid potential aggravation of neck symptoms from the exercise programs in patients with moderate or severe levels of reported neck pain and disability.

Participants were excluded if they had specifically trained their neck muscles in the preceding 6 months, if they experienced neck pain from nonmusculoskeletal causes, demonstrated neurological signs, or had any other medical disorder contraindicating physical exercise.

Ethical clearance for the study was granted by the University of Queensland Medical Research Ethics Committee and the study was conducted in accordance with the declaration of Helsinki. All participants received verbal and written information about the study and signed a consent form.

Equipment and Measurement Procedure

CCF muscle performance was measured in supine using a dynamometer (**FIGURE 1**) that measures muscle torque about the axis of rotation (AOR) of the C0-1 motion segment,[30] which lies in close proximity to the anterior mastoid process.[10,34,38] The axis of the dynamometer was aligned to the concha of the ear, as this best approximated the anterior mastoid process that is occluded from direct vision by the ear.[30]

The participant's CCF effort was resisted at the undersurface of the mandible by the dynamometer resistance arm, producing a torque measured in Newton-meters (Nm). A force platform monitored any tendency for the participant to push the head into, or lift it off of, the supporting surface, as such motions are thought to be a possible strategy to enhance CCF muscle torque.[29] Measurements of CCF muscle torque were recorded with the head in an anthropometric neutral craniocervical flexion/extension position (Frankfort plane, a vertical line that bisects the orbitale and the tragion)[24,25] that was visually determined by the investigator. The participant's knees and hips were positioned in 45° of flexion and the arms folded across the chest to minimize the effects of limb leverage.

Two custom-written LabVIEW programs (National Instruments Corporation, Austin, TX) recorded the CCF muscle torque data at 20 Hz. The first was for the measurement of isometric MVC and the second for endurance measurement of sustained torque at 50% of MVC (MVC_{50}). Feedback of CCF muscle torque was provided to participants on a visual display unit. All participants received standardized verbal encouragement during the dynamometry tests.

MVC TEST. Five trials were performed following a standardized warm-up procedure. A rest of 1 minute was given between repetitions. Participants were instructed to nod their head (yes-type action) such that their jaw pushed down onto the padded bar in an effort to maximally elevate the visual display graph. Following the MVC trials, a 5-minute rest was permitted before performing the endurance tests.

MVC_{50} TEST. Participants performed craniocervical flexion onto the resistance pad of the dynamometer to elevate the visual display graph to the marker indicating 50% of their MVC effort. Participants were asked to accurately maintain this level of contraction effort until fatigue prevented them from sustaining the contraction any longer. Participants were instructed to discontinue the test when they perceived an inability to sustain the contraction at the indicated intensity and the duration of this contraction was measured in seconds. No expectations were given to participants of any maximal time limit for the test and they were not informed that the LabVIEW program was set to terminate after a 10-minute period. Participants were warned that, while some discomfort associated with muscle fatigue was to be expected, they were to discontinue the test if they experienced their reported neck pain symptoms or pain in the jaw, head, or upper limbs.

Both dynamometry measurements have been shown to have good test-retest measurement reliability (ICC, 0.7-0.92).[26]

The investigator supervising the dynamometry measurements was blinded to participants' exercise intervention group to prevent potential measurement bias. Pre-exercise and postexercise intervention measurement sessions followed identical procedures with 1 exception. Torque amplitude for the MVC_{50} test performed following the 6-week exercise protocol (posttraining) were based on the MVC peak torque measurement from the pretraining testing session, not the peak torque measurement recorded in the posttraining testing session. In this manner, the MVC_{50} measures over the pretraining/posttraining sessions could be compared under the same load challenge and a direct analysis of performance change could be assessed.

Exercise Interventions

All participants in both exercise groups attended 1 session per week with an experienced musculoskeletal physiotherapist over the 6-week duration for a total of 6 sessions. All physiotherapists were experienced in teaching, supervision, and progression of both of the exercise protocols described below in a standardized manner. Participants in both groups were instructed to perform the exercise program twice daily. All exercise was performed free of any pain provocation. The physiotherapists closely monitored

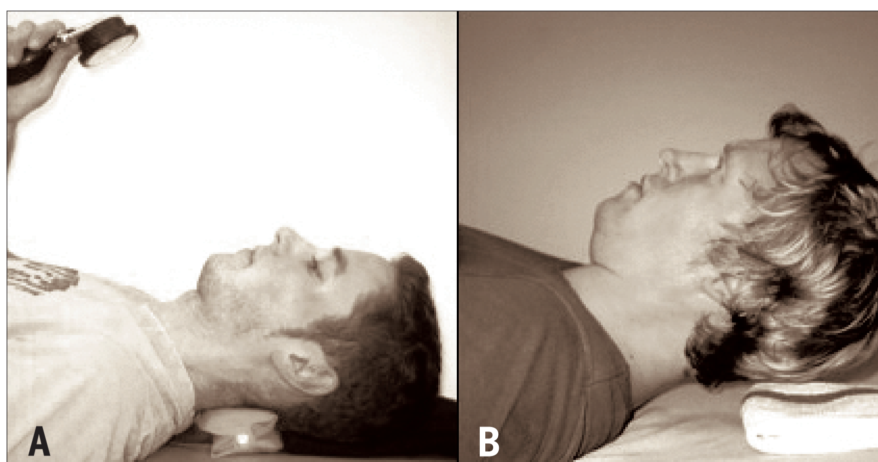

FIGURE 2. Movement characteristics of the craniocervical flexion exercise (CCFEx) (A) and cervical flexion exercise (CFEx) (B) protocols. The CCFEx exercise involves a specific craniocervical flexion movement (nodding-yes movement) of the head such that it remains in contact with the supporting surface and is graded with a pressure biofeedback device (Stabilizer; Chattanooga Group Inc, Hixon, TN). In contrast, the craniocervical spine is maintained in a neutral position, while the head is lifted off the supporting surface during a CFEx. This exercise protocol is graded according to a 12-repetition maximum.

the patients' responses to the exercise programs to ensure the avoidance of unwanted accumulative muscle fatigue that can occur when the exercise program progresses too aggressively. Participants were instructed in exercise only and no other form of intervention was provided.

CCFEX PROGRAM. (**FIGURE 2A**) This participant group specifically trained craniocervical flexion in the supine position using the protocol described by Jull et al.[14] In this program an emphasis was placed on first attaining the correct craniocervical flexion action, with minimal activity of the superficial cervical flexor muscles. Once the correct action had been achieved, participants were instructed in the use of the pressure biofeedback device to guide their training of the CCF muscle contraction at the various incremental levels of pressure (22 to 30 mmHg, progressively inner range positions). Participants trained to progressively increase the pressure increment at which their CCF muscle contraction could be sustained with control for a 10-second duration. Participants were instructed to perform 10 repetitions of the exercise at the level they could achieve, with short, intervening rest periods. A pressure biofeedback device was provided to each participant so that exercises could be performed at home.

CFEX PROGRAM. (**FIGURE 2B**) This participant group trained their CCF muscles by performing a controlled head lift exercise in the supine position. The head lift exercise was taught ensuring that the craniocervical spine was maintained in a neutral position while the head was lifted off the supporting surface. The emphasis of this exercise program was on improving the endurance of the cervical flexor muscles. Participants were initially tested on their 12-repetition maximum. If the participant could perform 12 repetitions lifting head weight, with fatigue experienced at the completion of the repetitions, they were instructed to begin lifting head weight only. If they were unable to perform 12 repetitions with head weight only, they were put in progressively inclined positions to reduce the effects of gravity until 12 repetitions could be performed. Conversely, if 12 repetitions were performed easily, 0.5-kg weights were incrementally added to the forehead until the 12-repetition maximum was found. Over the first 2 weeks the participants performed an initial conditioning program of 3 sets of the 12-repetition maximum repetitions, slowly building up to 3 sets of 15 repetitions. Over the final 4 weeks of the program, the participants' 15-repetition maximum was determined and practiced until 3 sets of 20 repetitions could be performed at this level, at which time the 15-repetition maximum level was reassessed and load progressed accordingly.[1]

Data Management and Statistical Analysis

Data were excluded for dynamometry measurements that reproduced participants' painful neck symptoms, or produced pain in the head, jaw, or upper limb, or if the participant found it too difficult to control the dual task of CCF and controlling dorsal head force on the supporting surface.

For the MVC measurements, the highest-amplitude torque measurement (Nm) of the 5 MVC trials was recorded as the MVC peak torque score for the testing session.

For the MVC_{50} test, 2 measures were extracted from each trial. The time (seconds) until the participant terminated the test was recorded as the time-to-task-failure measure.[8,11] The second measure, contraction accuracy, was calculated as the percentage of the recorded samples that remained within a previously established amplitude margin (±3%) on either side of the expected torque task for the duration of the test.[26,28] This calculation was performed using a custom-written LabVIEW program. The first 10 seconds of data for each test was discarded as this time was permitted for the participant to reach and stabilize the contraction. Contraction accuracy is a measurement of a participant's precision in sustaining a contraction effort and reflects, amongst other things, variables, such as muscle tremor, that may be associated with muscle fatigue.[8]

All data were grouped according to rehabilitative exercise group allocation (CCFEx, CFEx). An analysis of variance was used to evaluate the factors of group (CCFEx, CFEx) and time (pretraining, posttraining) on the indices of muscle performance (MVC, MVC_{50} [time to task failure, contraction accuracy]). Alpha was set at .05.

RESULTS

Adverse Effects of Exercise Interventions

There were no reported serious adverse effects or incidents resulting from either of the exercise interventions, and all 50 participants returned to complete their postexercise intervention outcome measurements.

Excluded Data

No data were excluded for the MVC measures. For the MVC_{50} test, data were excluded due to adverse effects (onset of painful symptoms during the testing procedure) (6 subjects from the CCFEx group, 4 subjects from the CFEx group) and inability to control the dual task (1 subject from the CCFEx group, 2 subjects from the CFEx group). Analysis of the MVC_{50} data was therefore performed on 20 (74%) participants in the CCFEx group and 17 (74%) participants in the CFEx group.

Group Comparison

All CCF muscle performance measurements demonstrated a significant improvement with respect to time (pre–exercise-postexercise intervention) in both groups (CCFEx, CFEx) ($P<.01$). On average both groups demonstrated a 0.6-Nm gain in MVC peak torque that corresponded to an 11% increase for the CCFEx group and a 12.2% increase for the CFEx group (**TABLE**). The CCFEx group improved its MVC_{50} time-to-task-failure measure by 18.3 seconds (37% improvement),

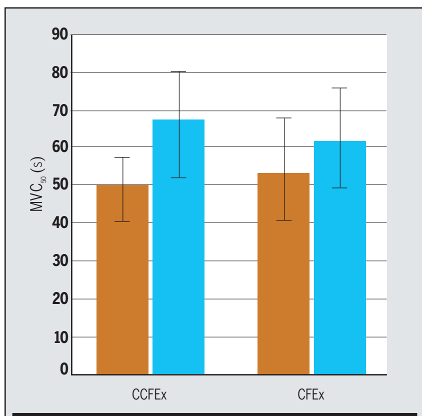

FIGURE 3. Mean (error bars, standard deviation) data for baseline (orange) and postexercise (blue) time to task failure for sustained contractions at 50% maximal voluntary contraction (MVC_{50}) on craniocervical flexion dynamometry. The 6-week exercise program consisted of either craniocervical flexion exercise (CCFEx) or cervical flexion exercise (CFEx). No significant group-by-time interaction was present ($P = .16$) for this measure. A significant ($P<.01$) baseline-to-postexercise difference took place in both groups.

compared to an 8.6-second (16% improvement) increase by the CFEx group (**FIGURE 3**). The contraction accuracy measurement at MVC_{50} showed similar improvement in both CCFEx and CFEx groups ($P<.01$), with increases of 7.1% and 9%, respectively.

No significant differences in CCF muscle performance was observed between the exercise intervention groups (CCFEx, CFEx) at baseline and after exercise intervention, as indicated by an absence of group main effects (MVC, $P = .09$; MVC_{50} time to task failure, $P = .99$; MVC_{50} contraction accuracy, $P = .08$), or group-by-time interactions (MVC, $P = .97$; MVC_{50} time to task failure, $P = .16$; MVC_{50} contraction accuracy, $P = .71$).

DISCUSSION

In this study, we compared the effect of 2 different exercise methods in training isometric CCF muscle performance. The results of the study indicate that isometric CCF muscle performance may be trained in patients with mild neck pain and disability, with either a CCFEx or a conventional CFEx program. We had hypothesized that the specificity of performance training (craniocervical flexion versus cervical flexion), and subsequent specificity of muscle activation training of the CCFEx program, would result in greater gains in isometric CCF muscle performance than a conventional CFEx program, particularly in the endurance test at moderate intensity of effort. Contrary to the initial hypothesis, both exercise protocols resulted in significant gains in isometric CCF muscle performance (MVC, MVC_{50}), with no significant difference between groups observed. We have shown in a previous EMG study that both isometric craniocervical flexion and cervical flexion muscle contractions elicit similar activation of the deep CCF muscles over a spectrum of contraction intensities (MVC, 50% of MVC, 20% of MVC).[27] Although the intensity of muscle contractions of the exercise protocols used in this study were not standardized according to MVC, it would appear that the contractile demands placed on the CCF muscles in both exercise protocols were adequate to result in similar isometric strength and endurance performance gains in patients with mild neck pain.

It should be noted that the findings of this study are limited to improvement of isometric CCF muscle strength and endurance only, and don't include the exercise effects on neck pain and disability. Caution must be taken when extrapolating the findings of this study to patients with higher levels of neck pain and disability to that included in the study. We purposefully included only participants with mild levels of reported neck pain and disability to avoid potential aggravation of symptoms due to the exercise programs, especially from the CFEx protocol, in which the weight of the head is lifted against gravity, potentially inducing large forces through pain-sensitive structures. It has been our clinical experience that the CFEx is often provocative of symptoms in patients with higher levels of reported neck pain and disability. In contrast, the head remains on the supporting surface during the CCFEx protocol, permitting the CCF muscles to be therapeutically challenged without the additional strain of lifting the head. Notwithstanding this, in this group of patients with mild neck pain and disability, neither exercise protocol resulted in exclusion of participants due to adverse effects of the exercise program, perhaps a consequence of the carefully graded prescription of exercise intensity for both exercise protocols as administered by the supervising physiotherapists. The choice of exercise prescription in clinical practice will also be dependent on factors such as the severity of the patients symptoms, the degree of CCF muscle impairment, and the patient's initial symptomatic response to exercise.

Future studies will need to investigate the underlying physiological mechanisms associated with improvements in CCF muscle performance following therapeutic exercise programs. Gains in isometric strength following rehabilita-

Craniocervical Flexor Muscle Performance*

	Craniocervical Flexion Exercise Group		Cervical Flexion Exercise Group	
Measure	**Pretraining**	**Posttraining**	**Pretraining**	**Posttraining**
MVC (Nm)	5.5 (4.9-6.1)	6.2 (5.6-6.7)	4.9 (4.2-5.5)	5.5 (4.9-6.0)
MVC_{50}				
Time to fatigue (s)	49.2 (40.8-57.3)	67.5 (54.0-81.1)	54.0 (40.6-67.3)	62.6 (49.2-75.9)
Contraction accuracy (%)	38.3 (31.4-45.1)	45.4 (37.5-53.3)	30.2 (23.8-36.5)	39.2 (34.5-43.9)

**Measurement means and 95% confidence intervals (pretraining and posttraining) for both exercise groups. Significant time effects (pretraining-posttraining) were found for all measures for both groups (P<.01). No group main effects at baseline or group-by-time interactions were observed.*

tion have been correlated with increases in cross-sectional area of neck muscles.[5,31] However, this may not explain the gains in MVC observed for both groups in this study (**TABLE**), particularly for the CCFEx group, who only ever performed relatively low-intensity exercise. Gains in MVC following only 6 weeks of therapeutic exercise, as performed in this study, may be more associated with neuromuscular adaptations such as greater synchronization of motor units,[4,23] altered sensitivity of muscle receptors,[20] and reduced recruitment of nonprimary muscles.[4] Further research is required to elucidate the characteristics of the adaptations brought about by these exercises.

There are limitations to the current study. The combination of large variability in the time-to-task-failure measure (between-subject variability of approximately 50% of mean group measurements)[26] and data exclusion rates (26% of data for the MVC_{50} measure were excluded) will have reduced the case for statistical group differences and risked the chance of a type II error. Additionally, the lack of significant group differences may reflect the sensitivity of the dynamometry measurements used in this study to detect the specific training effects of the exercise protocols used in the clinical trial. Adaptations in the neuromuscular system to training appear to be related specifically to the characteristics of the exercise, referred to as "specificity of training."[5] Changes in muscle performance may be specific to exercise characteristics, such as movement pattern, velocity of contraction, type of contraction, and joint angle.[18,21,32,33] Although both exercise programs had some characteristics specific to the isometric dynamometry tests, neither were identical, particularly with regard to characteristics such as joint angles, velocity, duration, and intensity of CCF muscle contractions. Additionally, there is also some evidence that isometric tests of muscular function are not sensitive to dynamically induced training adaptations,[31,39] as may have been expected with both exercise programs.

CONCLUSION

Impairment in CCF muscle performance appears to be a feature in some chronic neck disorders. The results of this study suggest that isometric CCF muscle performance can be retrained with either a specific CCFEx protocol or a conventional CFEx (head lift) program in patients with a mild level of reported neck pain and disability. Clinicians should keep these options in mind when prescribing exercise for a patient with mild neck pain who demonstrates CCF muscle impairment, but should apply caution to extrapolating the findings of this study to patients with higher levels of reported neck pain and disability. ◉

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