ORIGINAL ARTICLE

Training Mode–Dependent Changes in Motor Performance in Neck Pain

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ABSTRACT. O'Leary S, Jull G, Kim M, Uthaikhup S, Vicenzino B. Training mode–dependent changes in motor performance in neck pain. Arch Phys Med Rehabil 2012;93:1225-33.

Objective: To determine whether changes in motor performance after a course of exercise in patients with mechanical neck pain (MNP) were dependent on the primary behavioral demand of the exercise performed.

Design: Randomized controlled trial.

Setting: University laboratory.

Participants: Volunteers (N=60; 35 women, 25 men; mean age, 37.9y) with chronic MNP participated in the study.

Intervention: Exercise targeted to improve cervical motor performance including endurance training (ETr; n=20), coordination training (CTr; n=20), and active mobility training (n=20).

Main Outcome Measures: Changes in the cervical motor performance domains of strength, endurance, coordination, and active mobility were evaluated immediately after the 10-week training program, and at a 26-week follow-up.

Results: Between-group comparisons revealed significantly greater gains in endurance ($P<.02$) by the ETr group, and significantly greater gains in coordination ($P<.01$) by the CTr group. All 3 groups had improvement in pain ($P<.01$) and disability ($P<.01$).

Conclusions: Changes in motor performance in individuals with MNP in response to an exercise program were dependent on the specific mode of exercise performed, with minimal improvement in other domains of motor performance.

Key Words: Exercise therapy; Neck muscles; Neck pain; Rehabilitation.

A FEATURE OF THE HUMAN motor system is its plasticity and capacity to adapt to changing functional demands including those that are exercise induced. The process of exercise-induced adaptation of the motor system is multifactorial including neuronal[1] and muscle changes.[2] Adaptations to training appear to be specific to the mode of exercise training. Specific neuronal, muscle, and functional changes in motor output (changes in strength, endurance, and skill) in response to exercise appear to be dependent on the mode (primary behavioral demand) of training undertaken.[1-4] As such, it is recommended that exercise to train motor performance is prescribed specific to the desired enhancement in motor performance.

One area of rehabilitation where exercise is commonly prescribed with the intent of improving motor performance is in the management of chronic mechanical neck pain (MNP).[5,6] This practice is underpinned by evidence of an association between aberrant motor performance and chronic MNP,[7-10] and further justified by the demonstrated efficacy of cervical motor training in the management of MNP.[5,11,12] However, despite the general acceptance of motor training as a legitimate management strategy for MNP, its optimal implementation in the management of these disorders is still unclear. One challenge is the myriad of motor impairments reported in this patient group. Studies indicate that chronic MNP disorders may be associated with alterations in cervical motor behavior (timing and activation)[7,8,13-16] and changes in muscle structure (cross-sectional area, fatty tissue, fiber type),[7,9,17-20] as well as functional deficiencies in strength,[10,21,22] endurance,[10,22,23] precision and acuity,[10,24-26] and sensorimotor function.[27,28] What is unclear at this point is whether each of these various impairments requires specific retraining in patients with MNP. Moreover, it is unclear whether there is adequate improvement between the different domains of motor performance that would justify not having to address each motor impairment separately in the management of a patient with MNP.

Cervical spine studies that have investigated exercise-induced changes in motor performance between different domains of motor function in patients with MNP have shown mixed findings. Studies that have investigated the effects of a low-load craniocervical flexion training protocol (large element of coordination/skill training)[29] have shown this mode of exercise to also improve proprioceptive acuity of the neck[30] but to result in negligible improvements in flexor activation during a functional activity[31] or in flexor muscle strength.[32] Similarly, a specific flexor strength training protocol was shown not to

List of Abbreviations

AS	anterior scalene
CTr	coordination training
ETr	endurance training
MNP	mechanical neck pain
MTr	mobility training
MVC	maximal voluntary contraction
NDI	Neck Disability Index
RMS	root mean square
SCM	sternocleidomastoid
VAS	visual analog scale

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improve flexor muscle activation during a test of low-load craniocervical flexion.[33] While all trained motor behaviors may contain multiple elements of enhanced performance (improved strength, endurance, and skill) developed through extensive practice,[1] these studies to date suggest that exercise-induced changes in motor performance in patients with MNP are mostly specific to the mode of the exercise protocol. These findings have prompted us to perform further studies in an attempt to better inform exercise prescription for the management of chronic neck disorders.

We compared 3 different modes of cervical motor training (endurance, coordination, mobility) in patients with MNP to investigate whether changes in cervical motor performance are dependent on the primary behavioral demand of the exercise performed. Specifically, we hypothesized that changes in cervical motor endurance, coordination, and mobility will be specific to the mode of exercise training (ie, endurance, coordination, and mobility training, respectively). Because of the diverse motor impairments observed in patients with neck pain, we anticipate that the findings of this study will further inform clinicians as to the expected motor behavior outcomes of specific training protocols when managing these patients in the clinical setting.

METHODS

Study Design

A randomized trial with blinded outcome assessment compared the immediate (10wk) and midterm (26wk) effects of 10 weeks of cervical endurance training (ETr), coordination training (CTr), and mobility training (MTr) on cervical motor performance.

Participants

Participants for the study were recruited from the university and general community. Participants were eligible if they were aged 18 to 55 years, reported a history of neck pain of greater than 6 months' duration, scored between 10 and 15 points out of a possible 50 points on a Neck Disability Index (NDI),[34] and demonstrated positive findings on a physical manual examination of the cervical spine (altered joint motion and painful reactivity to palpation).[35] Only participants determined to have mild neck disability as rated using the NDI (participants' scores <15 points of a possible 50 points)[34] were included to avoid potential aggravation of neck symptoms from the exercise programs. Participants were excluded if they had specifically trained their neck muscles in the preceding 6 months, if they experienced neck pain or headache from nonmusculoskeletal causes, demonstrated neurologic signs, or had any other medical disorder contraindicating physical exercise. Participants within an age range of 18 to 55 years were accepted for both groups to ensure skeletal maturity and to minimize any confounding effects of advanced degenerative changes in the cervical spine.

If deemed eligible to participate and after consent, participants were randomly assigned to 1 of the 3 exercise intervention groups by a computer-generated randomization schedule by an independent investigator.

Ethical clearance for the study was granted by the university's 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.

Cervical Motor Performance Measurements

Strength and endurance measurement. Isometric craniocervical flexor strength and endurance were measured in a neutral flexion/extension position (Frankfort plane) in sitting using the NeckMetrix dynamometer.[36-38,a] This dynamometer resists participants' flexion efforts at the undersurface of the mandible, recording craniocervical flexion torque in newton meters about an axis aligned to the axis of rotation of the C0/1 motion segment (concha of the ear). Torque recordings from the dynamometer are displayed via a computer equipped with a custom-written Labview data acquisition program.[b] During testing, standardized visual feedback (display graph that elevates as torque increases) and verbal encouragement were provided to the participants. The participant's thorax was secured posteriorly by the seat of the dynamometer and anteriorly by a belt around the upper chest secured to the seat. During testing, the arms were placed by the participant's side to further minimize trunk motion during testing.

In the first instance, recordings were made of the participants' maximal isometric craniocervical flexor strength (maximal voluntary contraction [MVC]). Participants first performed a standard warm-up of 3 submaximal repetitions, which was followed by 3 trials of maximal contractions with 60 seconds of rest between each trial. The maximal torque value of the 3 trials was recorded as the participant's MVC score. Five minutes of rest was allowed before the commencement of the endurance test. For the endurance test, participants were required to sustain a craniocervical flexion effort at 50% of their MVC until they could no longer sustain the contraction (task failure), at which point the test was terminated. The duration of time that the participant sustained the contraction before task failure was recorded as the endurance measure (seconds).[10] These dynamometry measurements have been shown to have good test-retest reliability (intraclass correlation coefficient, .70–.94).[38]

An identical procedure was repeated at the 10- and 26-week follow-up sessions, with the exception that the endurance test was based on the MVC peak torque measurement from the pretraining baseline measure so that the measure could be compared under the same load challenge, and a direct analysis of performance change could be assessed.

Coordination measurement. Coordination (defined for the purposes of this study as muscle activity during a standardized task) of the cervical flexor muscles was assessed with surface electromyography during the low-load craniocervical flexion test in accordance with our established protocol.[39,40] This test is performed in 5 incremental stages of increasing craniocervical flexion range in the supine position. The subject was guided through the stages by feedback from an inflatable air-filled pressure sensor (Stabilizer[c]) placed behind the neck (pressure increases as the lordosis flattens with progressive craniocervical flexion). The pressure sensor was inflated to a baseline of 20mmHg, and the subject performed the 5 stages of the test (2-mmHg increments; range, 20–30mmHg). Participants were fully familiarized with the test. Pairs of Ag/AgCl surface electrodes[d] (11-mm disk, 3-mm diameter) were attached over the sternocleidomastoid (SCM; lower one third of the muscle) and anterior scalene (AS) muscles bilaterally.[8] The ground electrode[e] was placed on the upper part of the thoracic spine. Recordings of SCM and AS electromyographic activity were made as participants sustained an isometric contraction for 10 seconds at each stage of the test. There was a 10-second rest period between each stage of the test.

Electromyography signals were amplified (gain, 1mV), and band-pass filtered between 20 and 450Hz and sampled at

2048Hz (ASE16 amplifier[f]). A measure of electromyography signal amplitude was obtained by calculating the maximum root mean square (RMS) values using a 1-second sliding window for each stage of the test for both muscle groups (SCM, AS). For normalization purposes, the electromyographic amplitude for each craniocervical flexion test stage (22–30mmHg) was expressed as a percentage of the 1-second maximum RMS value obtained during a reference voluntary contraction (head lift). This reference contraction was used for normalization purposes, consistent with our previous studies,[8,31,33,39] to avoid issues concerning the use of MVC reference contractions for data normalization purposes in patients with painful disorders.[41-43]

Cervical range of mobility measurement. Range of movement was measured with a 3-space Fastrak System[g] and calculated with a customized Matlab software program.[h] Active cervical range of motion (degrees) was measured in 4 directions (flexion, extension, right and left axial rotation) from an upright neutral position of the head and neck, consistent with previous studies[37,44-46] in our laboratory. Participants were seated on a wooden chair with their shoulders supported on a backrest. The participants were familiarized with all test movements and practiced each movement once, with any unwanted movement of the shoulders or thorax corrected. From the starting position, participants were encouraged to move as far as possible each time at a comfortable speed before returning to the start position. Three trials were performed in each movement plane, and the mean of the values was used in the analysis.

Neck Pain and Disability Measurements

Measurements of patient-reported neck pain and disability were also recorded at the same time intervals as for the motor performance measures. Participants were asked to indicate their average neck pain intensity over the previous week by placing a mark on a 100-mm line bordered at one end by the words "no pain" and the other end by the words "worst pain ever."[47] Neck disability was measured at each time interval using the NDI.[48]

Exercise Interventions

Exercise regimens were conducted in a standardized manner over a 10-week period under the supervision of experienced physiotherapists specifically trained in teaching, supervision, and progression of the exercise protocols used in the study. Each participant received a total of 8 consultations with the physiotherapist over the 10-week period that included an initial consultation, followed by weekly reviews for the first 6 weeks, followed by a 2-week review at 8 weeks. The physiotherapists closely monitored the patient's responses to the exercise programs to ensure that unwanted accumulative fatigue that may have aggravated symptoms was avoided, while also ensuring that exercise was progressed adequately to maximize improvements in motor measures. Participants in all groups were instructed to perform the exercise program twice daily at home. The emphasis was to exercise at a level that was not provocative of symptoms. Compliance was encouraged by providing written instructions of the exercise program and subsequent updates for progressions, emphasizing to participants at each review the importance of persistent practice, and by strictly monitoring the performance of the exercises to ensure accurate performance within the capability of the individual. All participants in each group were also provided with written information regarding the maintenance of good spinal posture to facilitate the postural function of the cervical muscles. No other form of intervention was provided.

Mobility training. Participants practiced active movement exercises in an upright posture in the direction of cervical flexion, extension, and axial rotation (fig 1A). This exercise was progressed in terms of the amplitude of range through which the participant performed the exercise as dictated by comfort and capability, as well as the number of repetitions (3–10 repetitions) and sets (1–4 sets), for each direction of motion over the 10-week period.

Coordination training. Participants trained their flexor muscles in the supine position using the Stabilizer pressure biofeedback device[c] (fig 1B). An emphasis of this program was on attaining a coordinated craniocervical flexion action, with minimal activity of the superficial cervical flexor muscles. Training to minimize superficial muscle activity was directed by first ensuring that a correct craniocervical flexion pattern of movement was performed during training (craniocervical flexion is not the primary action of the superficial flexor muscles),[49] and then by instructing participants to self palpate the muscles to minimize activity during the exercise, consistent with clinical recommendations.[29] Once the correct action had been achieved, participants were instructed in the use of the pressure biofeedback device to guide their training of the craniocervical contraction effort at the various incremental levels of pressure (22–30mmHg, representing progressively

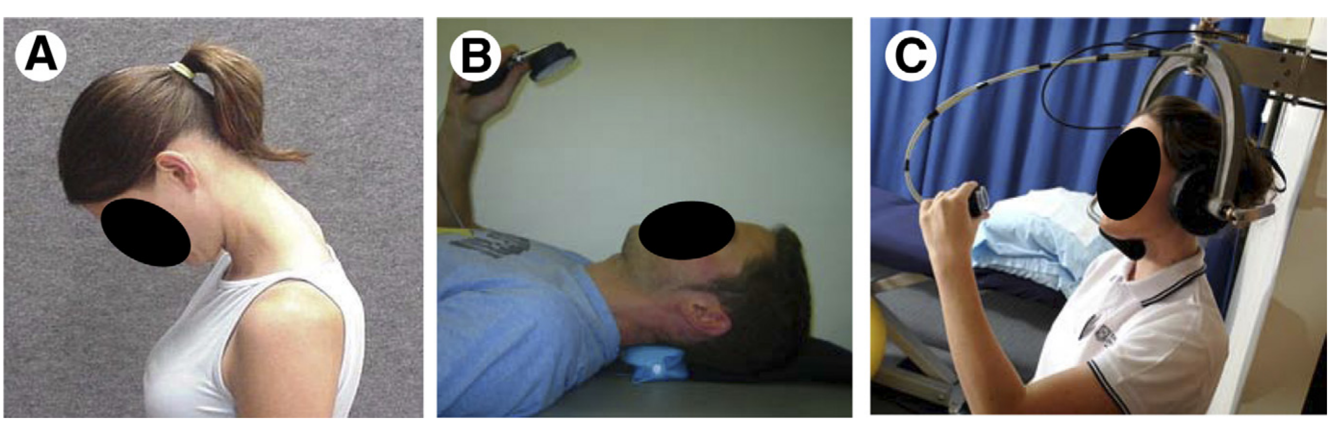

Fig 1. Exercise programs included active range of mobility training (A), coordination training of the craniocervical flexor muscles using a Stabilizer pressure biofeedback device (B), and endurance training of the craniocervical flexor muscles using a custom-built device (C).

inner range positions). Participants trained to progressively increase the pressure increment at which their craniocervical flexion 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.

Endurance training. Participants trained their flexor muscles in an upright posture with a purpose-built device setup within their home at the initial consultation (fig 1C). Participants performed isometric exercise at an intensity based on a percentage of their MVC, which was reevaluated at each supervised session. Participants initially performed sustained isometric craniocervical flexion contractions at intensities of 20% of MVC. Contractions were initially maintained for a 5-second period and repeated over 10 repetitions. Participants were instructed to extend the time of contraction progressively as able to a maximum of 20 seconds per contraction, while avoiding accumulative fatigue or the aggravation of symptoms. Participants were then instructed to maintain the total time of hold to 200 seconds, performing fewer repetitions and longer contraction times (eg, 4 × 50s, 2 × 100s) to facilitate improvement in isometric endurance. In the final 4 weeks of training if the participant was coping well with the exercise protocol, 5 to 10 repetitions at 50% of MVC sustained for 3 seconds were additionally performed, aimed to provide endurance training at a higher intensity of effort.

Participants in both the ETr and CTr groups also performed active movement exercise in the directions of cervical extension and axial rotation (in the same manner as the MTr group), to ensure that any group differences observed in outcome were not caused by the unidirectional nature of these 2 exercise protocols but rather the characteristics of the exercise mode (ie, coordination, endurance).

Procedure

Outcome measurements were recorded at baseline, immediately after the commencement of the 10-week exercise intervention period (10-wk follow-up), and 6 months later (26-wk follow-up). The investigator supervising the outcome measurements was blinded to the participant's allocated exercise intervention group to prevent potential measurement bias.

Data Management and Statistical Analysis

Sample size calculation. Sample size (N=60; 20 participants per group) was determined on the basis of our previous study[33] by using an identical measure of electromyography (coordination measure), comparing changes in performance in response to training between exercise groups while also providing the capacity to achieve a minimal detectable change in the secondary measure of NDI (measure of 5/50 points; α=.01, β=0.8).[48] Because of the gentle nature of the coordination measure, we believed that it would provide the most conservative calculation for sample size of all the motor measures, since differences in this measure were not expected to be large.

Group analysis. Group (ETr, CTr, MTr) means were established for all measures of motor performance (strength, endurance, coordination, range of mobility) and disability and pain (NDI, visual analog scale [VAS]) at the 3 time points (baseline, 10wk, 26wk). All analyses were performed on an intention-to-treat basis. An α of .05 was adopted.

Group data for the motor performance (strength, endurance, range of mobility, coordination [SCM and AS muscles]), as well as NDI and VAS measures, were compared with a linear mixed model with a within-subjects factor of time (3 levels: baseline, 10wk, 26wk) and a between-subjects factor of group (3 levels: ETr, CTr, MTr) with post hoc pairwise comparisons with Bonferroni corrections for multiple comparisons used to follow-up any significant effects. For the motor performance measure of coordination, an additional within-subjects factor of test stage (5 stages of 2mmHg within the test) was incorporated in the model. The linear mixed model was used for analysis because this style of modeling is similar to a repeated-measures analysis of variance but can accommodate missing data (electromyographic [RMS] and endurance data are prone to missing data points) from individual participants at 1 or more assessment points without losing the remainder of the participant's available data.[50] Because there were no side-to-side differences for RMS values for either the SCM or AS muscles, the average of both sides for each muscle was used for analysis.

RESULTS

Sixty volunteers with chronic neck pain participated in the study, and demographic data for each group are presented in table 1. Their progress through the study is depicted in figure 2. One participant in the CTr group withdrew from the study and did not complete either the 10- or 26-week follow-up measures because of other health issues. In the MTr group, 1 participant withdrew from the study because of an adverse immediate response to the exercise program (aggravation of symptoms) and did not return for outcome measures. Another participant in the MTr group did not return for the 26-week measures because of moving overseas. All participants in the ETr group completed their follow-up assessments.

Motor Performance Measures

Endurance and strength measurement. For the endurance measure, there were significant main effects for group ($P<.02$) and time ($P<.02$), and a significant group by time interaction ($P<.03$). Gains in craniocervical flexor endurance by the ETr group were significantly greater than those of the CTr or the MTr groups at 10 weeks ($P<.01$), and significantly greater than the MTr at 26 weeks ($P=.03$) but not the CTr group ($P=.06$) (tables 2 and 3).

The ETr group also gained significant increases in craniocervical flexion strength (see table 2) after 10 weeks of training that were maintained at the 26-week interval. Although only modest improvements in strength were achieved by the MTr and CTr groups (see table 2), there were no significant main effects for group ($P=.90$) (see table 3), time ($P=.08$), or group by time interaction ($P=.49$) for the strength measurement.

Coordination measurement. Changes in electromyographic activity in response to the incremental stages of the craniocervical flexion test (22–30mmHg) for the 3 groups at

Table 1: Comparison of the Intervention Groups at Baseline for Age, Sex, Height, Weight, and Pain History

Variables	ETr (n=20)	CTr (n=20)	MTr (n=20)
Age (y)	38.2±12.8	37.8±12.6	37.7±12.7
Sex (% women)	60	60	55
Height (cm)	168.9±8.3	167.3±24.8	170.8±6.9
Weight (kg)	69.2±16.4	78.2±28.8	73.1±17
Pain history			
Duration (y)	7.2±8.2	7.1±4.6	6.2±5
Traumatic onset (%)	25	15	15
Insidious onset (%)	75	85	85

NOTE. Values are mean ± SD or as otherwise indicated.

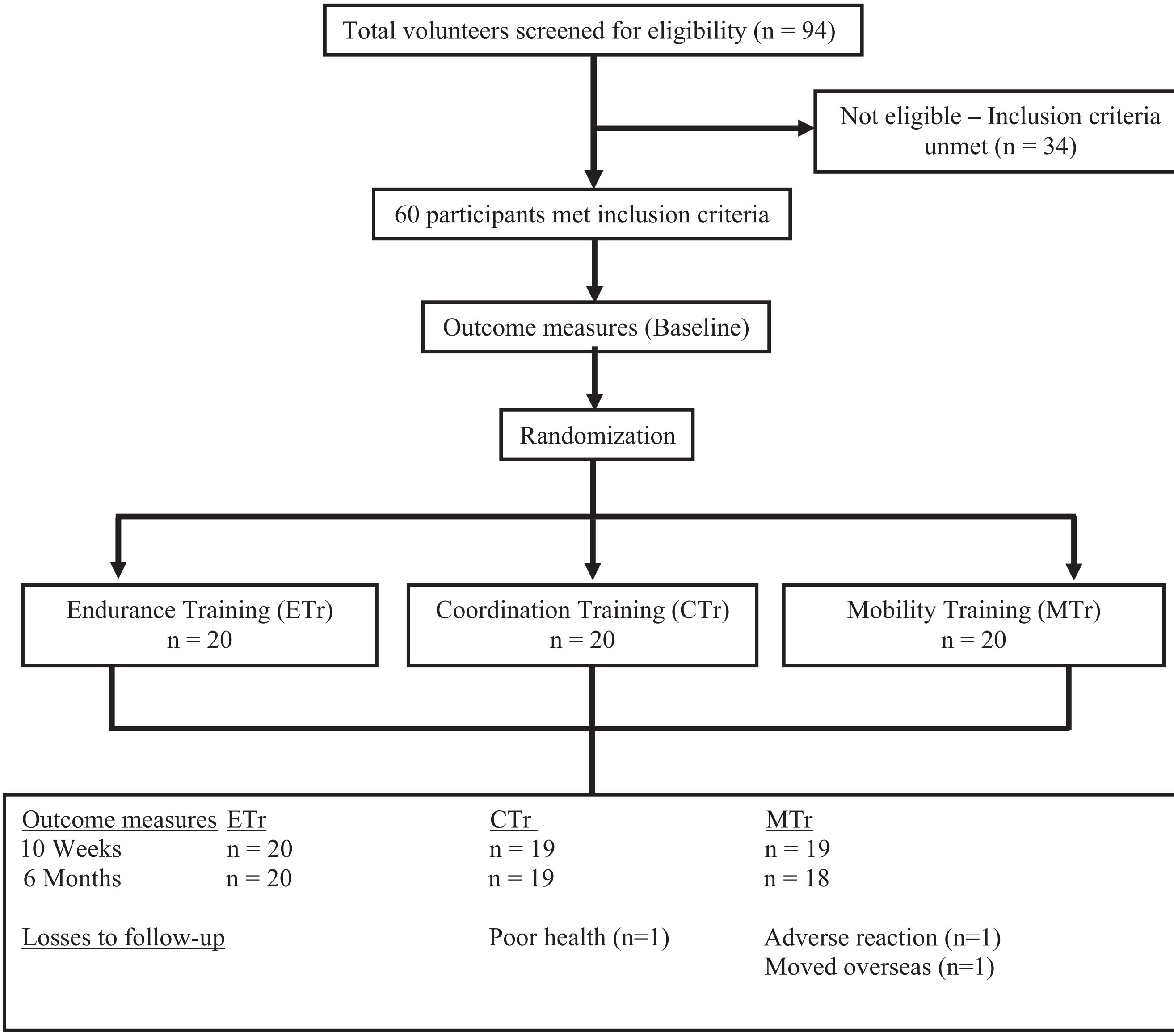

Fig 2. Participant progression through the trial including withdrawals and losses to follow-up.

baseline, 10- and 26-week intervals are depicted for the SCM and AS muscles in figures 3 and 4, respectively.

Significant interactions between group and time (P=.02), group and stage (P<.01), as well as main effects for group (P<.01), but not time (P=.16), were observed for the SCM electromyography signals. As indicated in figure 3, the CTr group demonstrated significant reductions in electromyographic activity compared with the ETr and MTr groups for stages 28 to 30mmHg of the test at the 10-week period (P<.01), and for stage 30mmHg of the test at 26 weeks (P<.03).

For the AS electromyography signals, there was a significant group by stage interaction (P<.01), and main effect for group approached significance (P=.05). No significant group by time (P=.10) interaction, or main effect for time (P=.30) was observed. Pairwise comparisons (see fig 4) indicated significantly greater reductions in AS electromyographic activity in the CTr group compared with the ETr and MTr groups for the 30-mmHg stage of the test at 10 (P<.03) and 26 weeks (P<.01).

Cervical range of mobility measurement. There were significant main effects of time for the range of mobility directions of flexion (P=.02) and left rotation (P=.02). There was no significant group by time interactions (P>.50) or main effect of group (P>.06) for range of motion in any of the directions tested (see table 3). There were significant main effects for time for the range of mobility directions of flexion (P=.02) and left rotation (P=.02). At the 10-week follow-up, range of motion had improved on average by 6.1% for the ETr group, 9.7% for the CTr group, and 4.1% for the MTr group; at 26 weeks these gains were 1.3%, 8.2%, and 4.3%, respectively (see table 2).

Neck Pain and Disability Measures

There was a significant main effect of time (P<.01) sustained over both follow-up periods for the measure of pain intensity (reduction in pain intensity), but no significant

Table 2: Scores for Motor Performance Outcome Measures of CROM, Strength, and Endurance of the CCF Muscles, Recorded at the 3 Time Intervals (Baseline, 10wk, 26wk) for the 3 Intervention Groups Follow-Up

Variable	Group	Scores		
		Baseline	10wk	26wk
CROM–flexion (deg)	ETr	42.4±7.7	42.9±8.8	44.2±8.0
	CTr	41.2±9.3	46.1±10.5	47.9±6.3
	MTr	43.6±10.6	42.8±7.4	47.7±5.7
CROM–extension (deg)	ETr	50.4±11.0	56.8±11.7	52.9±12.1
	CTr	46.1±12.6	51.3±12.9	50.7±12.2
	MTr	49.5±15.7	53.3±13.5	52.5±13.6
CROM–right rotation (deg)	ETr	58.1±7.4	62±8.8	56.6±9.2
	CTr	59.8±9.6	63.1±9.9	59.8±9.7
	MTr	59.1±8.0	61.1±9.6	58.8±7.5
CROM–left rotation (deg)	ETr	65.3±7.8	67.8±7.3	64.5±10.7
	CTr	61.1±9.6	67±8.5	64.8±8.2
	MTr	66.1±9.4	70.9±8.6	67.9±8.3
Strength–CCF (Nm)	ETr	8.9±3.9	11.9±4.5	12.3±5.9
	CTr	10.6±3.9	10.3±4.2	11±4.7
	MTr	9.9±4.4	11.3±5.1	11.7±4.5
Endurance–CCF (s)	ETr	33.9±16.0	62.4±57.5	64.2±56.1
	CTr	29.1±12.7	32.5±20.7	35.8±17
	MTr	31.8±13.0	32.5±13.5	33±16.1

NOTE. Values are mean ± SD.
Abbreviations: CCF, craniocervical flexor; CROM, cervical range of motion.

group effect (P=.80) or group by time interaction (P=.30) (tables 4 and 5). Similarly, there was a significant main effect for time (P<.01) sustained over both follow-up periods for the measure of NDI (reduction in disability), but no significant group effect (P=.30) or group by time interaction (P=.60).

DISCUSSION

The findings of this study support our hypothesis and suggest that exercise-induced changes in motor performance in patients with MNP are dependent on the mode of the exercise intervention, with modest improvement to other domains of motor function that are not representative of the primary behavioral demand of the exercise. Specifically, the ETr group acquired much larger gains in the endurance motor performance measurement (84%–90% increase) than the other training groups, with some carryover improvements in strength (35% increase), but acquired no gains in coordination performance. With respect to a lack of change in the coordination measure, these findings are similar to those of a previous study[33] in our laboratory that used a combined strength/endurance training protocol of the cervical flexors. However, in contrast to this previous study in which the flexor muscles were trained using a head-lift exercise (combined craniocervical and lower cervical flexion),[33] we had anticipated that this current ETr protocol may have had more impact on the measurement of coordination, as biomechanically both the ETr exercise (although isometric) and the coordination measurement were specific to the action of craniocervical flexion. However, changes in the measurement of coordination in response to the ETr protocol were not evident.

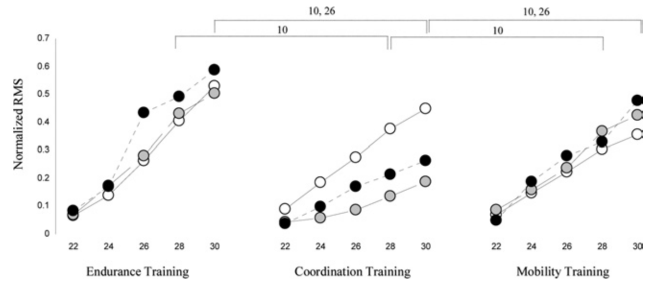

Fig 3. Electromyographic activity (normalized RMS values) of the SCM muscles during the progressive stages of the craniocervical flexion test (22–30mmHg) for all 3 training groups. The brackets denote significant between-group differences for a single stage of the test at 10 weeks (10) and/or 26 weeks (26).

Table 3: Group Mean Differences (95% CI) for the Outcome Measures of CROM, Strength, and Endurance of CCF Muscles at the 3 Measurement Time Points (BS, 10wk, 26wk) for the 3 Intervention Groups

Variable	Time	Mean Difference (Lower to Upper Limits)		
		ETr vs CTr	ETr vs MTr	CTr vs MTr
CROM–flexion (deg)	BS	−1.2 (−7.7 to 5.4)	1.2 (−5.3 to 7.8)	2.5 (−4.1 to 9.0)
	10	3.4 (−3.2 to 10.0)	0.1 (−6.5 to 6.7)	−3.2 (−9.9 to 3.4)
	26	2.7 (−4.7 to 10.0)	3 (−4.3 to 10.4)	0.4 (−6.9 to 7.6)
CROM–extension (deg)	BS	4.4 (−5.5 to 14.2)	0.9 (−8.9 to 10.8)	−3.5 (−13.3 to 6.4)
	10	5.7 (−4.2 to 15.7)	3.5 (−6.5 to 13.4)	−2.3 (−12.3 to 7.8)
	26	3.2 (−7.5 to 13.9)	1 (−9.7 to 11.7)	−2.2 (−12.9 to 8.5)
CROM–right rotation (deg)	BS	1.7 (−5.1 to 8.5)	1 (−5.8 to 7.9)	−0.7 (−7.5 to 6.2)
	10	0.8 (−6.1 to 7.7)	−1 (−7.9 to 5.9)	−1.8 (−8.7 to 5.2)
	26	1.1 (−6.3 to 8.5)	1.5 (−5.9 to 8.9)	0.4 (−7.0 to 7.8)
CROM–left rotation (deg)	BS	4.3 (−2.5 to 11.0)	−0.7 (−7.5 to 6.0)	−5 (−11.8 to 1.7)
	10	0.9 (−5.9 to 7.7)	−3 (−9.8 to 3.9)	−3.9 (−10.8 to 3.0)
	26	1.4 (−6.0 to 8.7)	−2.7 (−10.1 to 4.7)	−4 (−11.4 to 3.3)
Strength–CCF (Nm)	BS	−1.7 (−5.3 to 1.8)	−1 (−4.5 to 2.5)	0.7 (−2.8 to 4.2)
	10	1.3 (−2.2 to 4.9)	0.8 (−2.8 to 4.3)	−0.6 (−4.1 to 3.0)
	26	0.9 (−2.8 to 4.6)	0.4 (−3.3 to 4.0)	−0.5 (−4.2 to 3.2)
Endurance–CCF (s)	BS	4.2 (−18.9 to 27.4)	1.5 (−21.7 to 24.7)	−2.7 (−24.8 to 19.4)
	10	30.7 (7.7 to 53.7)*	30.1 (7.3 to 52.9)*	−0.6 (−23.7 to 22.5)
	26	23.9 (−0.6 to 48.4)	26.2 (1.8 to 50.6)*	2.3 (−21.9 to 26.4)

Abbreviations: BS, baseline; CCF, craniocervical flexor; CI, confidence interval; CROM, cervical range of motion.
*Denotes significant between-group difference (P<.05).

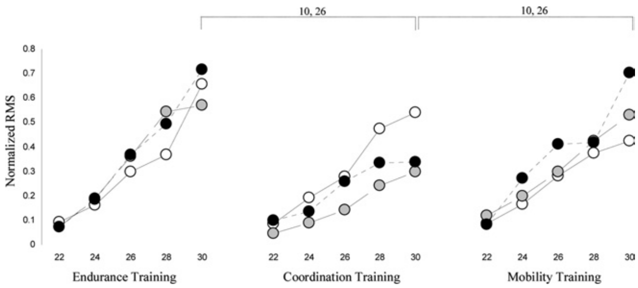

Fig 4. Electromyographic activity (normalized RMS values) of the AS muscles during the progressive stages of the craniocervical flexion test (22–30mmHg) for all 3 training groups. The brackets denote significant between-group differences for a single stage of the test at 10 weeks (10) and/or 26 weeks (26).

Also consistent with our hypothesis were the significant improvements in the coordination measure (reduced superficial muscle activity) after exercise recorded in the CTr group compared with the ETr and MTr groups. The observed improvements were most evident in the higher intensity levels (28 and 30mmHg) of the test (see figs 3 and 4), consistent with previous reports of greater differences in muscle activity in patients with neck pain compared with controls in these higher levels of the test.[8,39,40] Despite the CTr group acquiring larger changes in coordination (particularly measures from the SCM muscle) compared with the other groups, this group attained a negligible change in strength (see table 2) and modest improvements in endurance (11%–23% increase). Interestingly, these improvements were not as high as in a previous study[51] in our laboratory investigating the CTr protocol in MNP in which participants attained an 11% and 37% improvement in strength and endurance, respectively, using a similar dynamometry measurement protocol. Discrepancies between the magnitude of improvement in performance between these studies may be due to several factors including different participant populations, different intervening therapists, and some methodological difference in dynamometry measurement (dynamometry performed in supine position in previous study[51]). Notwithstanding this, the salient point in this study is that while both the ETr and CTr exercise protocols achieved superior training effects specific to their mode of application compared with the other training protocols, improved performance in other domains of motor performance were modest at best. In the management of MNP disorders, clinicians should not assume that one mode of exercise will address all potential motor impairments adequately. Decision making in exercise prescription for patients with MNP should consider all specific impairments identified in an individual and regularly monitored to ensure adequate improvements are being acquired.

The findings of this study are consistent with observations from mechanistic studies that indicate that neuronal, muscle, and functional changes after training are dependent on the specific behavioral demands of the training tasks.[1-4] For example, a review by Adkins et al[1] has described specific neuronal adaptations to training that are dependent on whether the training is focused on skill acquisition (enhanced synaptic formation, altered motor cortex movement representations), endurance training (altered formation of blood vessels in motor cortex, no alteration in motor map organization or synapses), or strength training (altered spinal motoneuron excitability, enhanced synaptic formation within spinal cord, no effect on motor map organization). Similarly, different responses in muscle have been described in response to endurance training (increased mitochondrial density, increased capillary density, and fiber transition from fast to slow)[3,52,53] to that for strength training (stimulates synthesis of contractile proteins responsible for muscle hypertrophy and increases in maximal contractile force output).[2] These mechanistic studies provide some insight into the physiologic mechanisms that potentially underlie the exercise mode–specific adaptations observed in our study, particularly in response to the CTr (large component of skill training) and ETr protocols.

No differences between groups were observed for the cervical range of mobility measure. Small changes in range of motion were achieved by all groups. Overall changes in range of mobility were clinically modest (maximum average, 6.6°) and perhaps represent a ceiling effect, as only mild deficits were evident in this measure at baseline in this patient population with mild neck disability. Interestingly, there was a tendency for greater gains in flexion range for CTr compared with MTr at 10 weeks (see table 2). It is interesting to speculate that the CTr exercises, which involve gentle repeated and sustained upper cervical flexions, may improve flexion mobility by inducing changes in the posterior soft tissue elements of the cervical spine, such as, for example, relaxation in tone of the extensor muscles or hysteresis of noncontractile tissues.

All 3 groups achieved similar improvements in pain and disability measures. There was a tendency for greater reductions in levels of reported neck pain for the CTr group over both the ETr and MTr groups, but only at the 10-week period (see table 4). Only the CTr group attained a change in the pain intensity (CTr group, 19.2mm; ETr, 9.1mm; MTr, 10.1mm) well beyond that considered to be a clinically significant change (12mm [95% confidence interval, 9–15mm]).[47] We have shown in a previous study[54] that the CTr exercise protocol has immediate pain-modulating properties (hypoalgesia to mechanical stimuli) greater than that of a higher load endurance exercise protocol. Comparison of these exercise conditions with respect to their impact on pain and disability should be made with caution because of the inclusion of participants with only mild levels of self-reported neck disability (participants' scores of <15 of a possible 50 points),[34] which was a purposeful inclusion criterion to avoid potential aggravation of neck symptoms (and potential subsequent losses to follow-up) from the exercise programs in this relatively small trial investigating training-induced motor effects. Further studies are now required that encompass individuals of varying clinical severity (mild to severe disability/pain) so as to investigate the impact of severity level on motor training.

Study Limitations

There are some further limitations of this study. Although all participants received 8 supervised sessions of exercise over 10

Table 4: Scores for the Clinical Outcome Measures NDI and PVAS, Recorded at the 3 Time Intervals (Baseline, 10wk, 26wk) for the 3 Intervention Groups Follow-Up

		Scores		
Variable	Group	Baseline	10wk	26wk
NDI (points/50)	ETr	11.0±2.2	6.1±4.3	7.5±4.7
	CTr	9.8±2.1	5.4±3.0	7.3±4.1
	MTr	10.5±2.5	7.6±3.3	7.3±3.7
PVAS (100-mm scale)	ETr	29.9±14.5	20.9±18.0	21.7±13.0
	CTr	33.2±13.0	14.0±10.2	22.6±16.9
	MTr	30.6±12.1	20.5±11.1	16.9±11.2

NOTE. Values are mean ± SD.
Abbreviation: PVAS, pain visual analog scale.

Table 5: Group Mean Differences (95% CI) for the Outcome Measures of NDI and PVAS at the 3 Measurement Time Points (BS, 10wk, 26wk) for the 3 Intervention Groups

Variable	Time	Mean Difference (Lower to Upper Limits)		
		ETr vs CTr	ETr vs MTr	CTr vs MTr
NDI (points/50)	BS	−1.7 (−1.4 to 3.9)	0.5 (−2.1 to 3.1)	−0.8 (−3.4 to 3.9)
	10	0.8 (−1.9 to 3.4)	−1.6 (−4.2 to 1.2)	−2.4 (−5.0 to 0.3)
	26	0.3 (−2.4 to 2.9)	0.1 (−2.6 to 2.7)	−0.2 (−2.9 to 2.6)
PVAS (100-mm scale)	BS	−3.3 (−13.7 to 7.2)	−0.7 (−11.1 to 9.7)	2.6 (−7.9 to 13)
	10	6.9 (−3.6 to 17.5)	0.1 (−10.4 to 10.6)	−6.8 (−17.5 to 3.9)
	26	−0.8 (−11.5 to 9.9)	4.7 (−6.1 to 15.5)	5.5 (−5.3 to 16.3)

Abbreviations: BS, baseline; CI, confidence interval; PVAS, pain visual analog scale.

weeks, most of the prescribed exercise sessions were to be performed within the home twice daily, and therefore we cannot be certain as to the level of participant compliance to the prescribed program. Notwithstanding this, compliance was encouraged by the provision of comprehensive documentation detailing the progressive program, and with strict monitoring and encouragement provided by the supervising physiotherapist at the regular review sessions. The findings of this study are also limited to patients with chronic MNP, and therefore findings cannot be extrapolated to patients with neck pain disorders of other etiologies such as whiplash injuries. This study also investigated only 3 modes of training. Within the scope of rehabilitation there are many other modes of motor training available to the clinician (eg, strength, power), as well as different applications of the studied modes (eg, dynamic endurance, different load intensities) that could be explored regarding their training effect. Additionally, training modes were not tailored to the specific deficits of the individual patients and instead were randomly allocated. Greater associated changes in motor performance, as well as pain and disability, may have been achieved if, for example, CTr was allocated to those patients showing the greatest baseline deficits in coordination, or alternatively ETr given to those patients with the greatest baseline deficits in isometric performance. Future studies will need to investigate whether exercise specifically tailored to an individual's greatest baseline deficits results in greater changes in motor performance and clinical outcomes.

CONCLUSIONS

For clinicians prescribing exercises for patients with mechanical neck disorders, the results of this study have shown that changes in motor function appear to be specific to the mode of training. Clinicians need to be aware that improvements in domains of motor performance other than those aligned with the primary behavioral demand of an exercise protocol may not be adequately acquired. Different patients may require different exercise protocols depending on their presenting motor impairments. To ensure optimal exercise prescription, clinicians should monitor the response of their patients to exercise in terms of changes in patients' motor abilities in addition to their reported levels of neck pain and disability.

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Suppliers

a. NeckMetrix dynamometer; Uniquest, University of Queensland, Brisbane, Australia, 4072.
b. Labview 6i Virtual Instruments; National Instruments Corp, 11500 N Mopac Expwy, Austin, TX 78759-3504.
c. Chattanooga Group Inc, DJO Global, 1430 Decision St, Vista, CA 92081.
d. Grass Telefactor; Astro-Med Inc, Astro-Med Industrial Park, 600 E Greenwich Ave, West Warwick, RI 02893.
e. 3M Corporate Headquarters, 3M Center, St Paul, MN 55144-1000.
f. LISiN Bioengineering Center, 22/H 10138, Torino, Italy.
g. Polhemus, 40 Hercules Dr, PO Box 560, Colchester, VT 05446.
h. MathWorks Inc, 3 Apple Hill Dr, Natick, MA 01760-2098.