Comparison Between the Velocity-specific Exercise and Isometric Exercise on Neck Muscle Functions and Performance: A Randomised Clinical Trial

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Research article

Keywords: peripheral joint muscles, spinal muscles, isometric exercise, cervical muscle, healthy adults

DOI: https://doi.org/10.21203/rs.3.rs-44939/v1

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Abstract

**Background:** Evidences showed that the additional benefits of velocity-specific exercise for improving functions of peripheral joint muscles. Its effects for spinal muscles is yet to be investigated. This study aimed to compare the effects of velocity-specific exercise to isometric exercise on cervical muscle functions and performance in healthy adults.

**Methods:** Thirty healthy adults received either a 6-week velocity-specific (VSE, n=15) or isometric exercise program (IE, n=15) of their neck muscles. Cervical muscle functions and performance were assessed pre- and post-program, using isokinetic assessment, electromyography and cross-sectional area assessment of deep neck muscles. A self-reported level of difficulty and post-exercise soreness was also recorded during the program.

**Results:** Both exercises programs showed significant increase in cross-sectional area of longus colli and semispinalis capitis; EMG amplitude in sternocleidomastoid and cervical erector spinae, and flexion and extension torque values, at reassessment, without between-groups difference. However, correlation between extension torque and EMG amplitude of cervical erector spinae increased in both groups and a significant correlation found in VSE group post-program. No significant differences found between groups on the self-reported scales.

**Conclusions:** Both exercises promoted cervical muscle functions and performance significantly with velocity-specific exercise contributes to a greater enhancement of torque production efficiency of superficial neck muscles. This novel exercise may consider as a safe alternative for neck muscle rehabilitation. Further study to examine the effects of velocity-specific exercise in symptomatic individuals to unravel its potential application and benefit for promoting the functional recovery is recommended.

**Background**

Nonspecific neck pain is the fourth leading cause of disability, with an annual prevalence rate exceeding 30% [1]. It was shown that as much as 50% of the patients would continue to experience some degree of neck pain in one-year period [1, 2].

People with neck pain showed various forms of neuromuscular dysfunctions in their neck muscles [3–5]. Falla et al. (2004) revealed increased activity of the superficial neck flexors, namely the Sternocleidomastoid and Anterior Scalene in symptomatic individuals, even at low load task execution. Over-activity of superficial neck flexors displayed in individuals with neck pain represents one of the altered motor control strategies to compensate the neuromuscular deficiencies such as weakness, inhibition and delayed activation of deep neck muscles. These neuromuscular deficiencies have been suggested as a lack of motor control and postural stability of the neck [4, 5]. It was suggested that restoring optimal neck muscle synergy and muscle endurance helps patients in relieving neck pain.
Therefore, training the deep neck muscles (i.e. longus colli, multifidus and semispinalis capitis and cervicis) and optimising the neuromuscular efficiency may possibly help promote rehabilitation outcomes of neck pain. Evidence from systemic review indicated that exercise had medium and significant pain reduction effects in both short term and intermediate term [6]. However, most included exercise protocols used shoulder exercises, isolated deep neck muscle activation, isometric exercises and isotonic exercises of the neck, despite velocity specific exercises (VSE) being found to have additional benefits for rehabilitation of the muscles at the peripheral joints [7, 8].

VSE might be useful since they seemed more functional to daily activities compared to isometric exercises (IE) [9, 10]. Daily activities often involve movement of the neck and IE are less effective in terms of motor control in neck movements. There may also be increased benefits in improving neck muscle function such as improving the contractility the muscles related to the greater level of mechanical stimulus acting on muscle tendons when exercise is performed at faster speed [8]. Training of velocity specific and explosive muscle contractions improved torque production at wider range of motion, compared with sustained contractions [11]. Moreover, VSE seemed to be superior to IE in reducing joint pain in peripheral joints. It was shown that isokinetic exercise had greater effect on pain reduction when compared with IE in participants with knee osteoarthritis [7]. The movement during the exercise increases substance exchange within the joint and reduces pain. There were some concerns of excess shearing force produced by neck muscles during VSE at high speeds. It was found that there was high shearing force during high-speed eccentric contraction from isokinetic efforts of knee flexors [12]. However, it would generally be safe if exercise speeds were not too high and the participants are healthy without any joint laxity. By ensuring the safety of exercise through limiting the speed and the shearing force produced by neck protraction and retraction, VSE might be a better alternative to neck IE.

There were no previous researches studying the effects of VSE on neck, although they seemed to have additional benefits over IE. Therefore, the aim of this study is to find out whether VSE is better or of similar efficiency to IE in healthy individuals through comparison of neck function, performance and deep muscle size. The results could help provide insights in research of neck exercises to determine if VSE of the neck are safe to perform and effective to promote neck muscle functions and performance in healthy participants. It may further provide clinical implications of using VSE in neck pain rehabilitation.

**Methods**

**Study design**

This study was a single-blinded randomized controlled trial comparing the effects of a course of velocity specific exercises (VSE) and isometric exercises (IE) on the functions and performance of the neck muscles.

**Participants**
Thirty adults (21 Males, 9 Females), aged from 19 to 23 whom were asymptomatic in their neck region for the last 12 months, were recruited by convenient sampling at University campus. Individuals were excluded if they reported to have any of the following conditions: vestibular or sensory abnormalities; vertebral artery insufficiency; previous trauma or surgery of the brain or spine; known cervical orthopaedic pathology; infectious disease; inflammatory, systemic or neoplastic origin; or any contraindication for performing neck strengthening exercise. Ethics approval was obtained from the Departmental Research Committee of the Hong Kong Polytechnic University, and written informed consent was gained from each participant. This study has obtained the clinical trial registry (Registry number: ChiCTR2000037837) and all assessments were conducted at the Clinical Research Laboratory of The Hong Kong Polytechnic University between June and November 2019.

**Experimental procedures and measurements**

After completing baseline assessments, participants were randomly allocated to the VSE group or IE group by drawing lots. Participants were blinded to the allocation of the exercise type. Fig. 1 shows the study design.

Mid-term follow-ups were conducted after week 3 to ensure movement quality and prescribe elastic band. Reassessments with the same protocol were conducted after week 6. The function and performance of the neck muscles were assessed by electromyography (EMG) amplitude and torque production during neck flexion and extension phases in isokinetic testing, and the size of the deep neck muscles was assessed by ultrasonography.

**EMG activity of the neck flexors and extensors during isokinetic assessment**

Standardised skin preparation, which included hair removal, light abrasion using sandpaper and cleansing of skin using alcohol swab and the electrode-skin impedance was <10kW. The placement of surface EMG electrodes have been reported by Lascurain-Aguirrebeña et al. [13] and recommended by SENIAM [31]. Surface EMG of Sternocleidomastoid (SCM) and Cervical Erector Spinae (CES) were measured at a sampling frequency of 1024 Hz (Noraxon Telemyo Wire system 9000, USA Inc.) using the bipolar disposable Ag–AgCl disc-shaped electrodes of 10 mm diameter with 20 mm inter-electrode distance. For SCM, electrodes were placed adjacent to a point 30% of the distance from the sternal notch to the mastoid process, along the direction of muscle fibres. For CES, electrodes were placed 2 cm lateral to the spinous process of C4-5 spinous process, over the muscle bulk, along the direction of muscle fibres.

For comparison of the effort of the activation between muscles and participants, the EMG amplitude was normalized to the Maximal Voluntary Contraction (MVC) of the respective muscles. MVC value of SCM and CES were recorded 3 times each in supine and prone position respectively using isometric neck
contraction against manual resistance at mid-range. The mean of the two peak EMG amplitude during flexion phase and extension phase of the two isokinetic test trials of the neck flexors and extensors was taken and displayed as %MVC. Cervical movement was measured by inertial motion sensor system (MyoMotion, Noraxon, USA Inc.) at a sampling frequency of 100 Hz during the isokinetic assessment system for a better understanding of EMG and torque relationship. Two sensors were placed, one on the forehead, one on C7 spinous process.

**Torque performance of the neck flexors and extensors during isokinetic assessment**

Torque values of the flexion and extension phase were measured using isokinetic assessment system (CYBEX isokinetic dynamometer) (Fig. 2). The participants were securely stabilized on a wooden chair with straps to enable isolated cervical movements from the trunk. The fulcrum of the dynamometer was aligned at the C7 level. The resistance pad was placed at the occiput area with straps across forehead. Head weight of the participants were recorded during calibration to normalize the torque production value by eliminating gravity effects. Range of motion for testing was set individually with an adjustment of 10 degrees short from their end-range to avoid excess load or shearing force acting on the neck during testing. The maximal isokinetic torque was determined at 30°/s angular velocity. Participants were asked to familiarize with the isokinetic testing procedures before the actual test. After the practice, 2 cervical isokinetic test trials with participant moved through their neck extension to flexion range were performed for 5 repetitions, with 1-minute rest between trials. Participants were encouraged to execute the test as hard as they could while maintaining chin tucked to avoid excessive neck protraction during the trial. At least 3 peak values from each trial would be taken and the mean would be obtained as the torque value.

The integrated analysis of the value of torque and EMG amplitude during flexion and extension phase offers the evaluation of changes in the neuromuscular efficiency between the deep and superficial muscles of the neck in response to neck exercise program.

**Cross-sectional area of the deep neck flexors and extensors assessment using ultrasonography**

Ultrasound scanning of the cross-sectional area (CSA) of deep cervical flexors, i.e. Longus Colli (LC) and deep cervical extensors, i.e. Semispinalis Capitis (SC) were measured by the ultrasound imaging unit (LOGIQe, GE Healthcare) using the B mode application, at a depth of 3–4 cm with the linear transducer frequency set to 8 MHz was used (Fig. 3). Measurement of the cross-sectional area of each muscle was taken twice and the mean was used for analysis. For longus colli, participants were placed in supine with head supported by pillow. C4 in anterior neck was estimated and marked by posterior neck palpation. Bifurcation of carotid artery was found to ensure C4 level was identified. The assessor then moved the probe distally until the bifurcation disappeared. The image of LC was taken at that position.
For semispinalis capitis, participants were placed in prone position and C4 spinous process was marked and transducer was placed lateral to the marking. The third muscle layer is SC. The bright line is the fascial layer and the area enclosed by the line is the CSA of SC, as previous study described [14].

Implementation of two exercise programs

**Velocity-Specific Exercise Program (VSE)**

For VSE group, participants were instructed to perform neck flexion and extension exercise 3 days/week for 6 weeks. The neck flexion exercise was performed in supine while neck extension exercise was in 4-point kneeling position. Participants were required to maintain the chin tucked-in throughout the flexion exercise. 60 beats per minute (BPM) was selected as the velocity of neck movement during both exercises. The speed was determined by the data collected in our preliminary investigation of the neck movement velocity during common daily activities.

A metronome set at 60 BPM was used. At the first “beep”, participants would start to perform the exercise from neutral position. By the time that their neck reached the end range of either flexion or extension, the participants should hear another “beep”. After that, they should move their neck from end range position to neutral position at the exact time of another “beep” (Fig. 4a-c). The above procedures were repeated 6 times as one set for 3 sets, with 1-minute rest between sets.

**Isometric Exercise Program (IE)**

For IE group, exercise of the same frequency was performed (Fig. 5a-c). Participants were asked to maintain their neck at mid-range position, with chin tucked-in in supine and mid-range position in 4-point kneeling respectively for 12 seconds, repeated for 3 sets, with 1-minute rest between sets.

**Progression of exercises**

Weekly progression of the exercise was made after week 3 according to the performance and responses from the individual. For week 1-3 period, participants were asked to perform the exercise with body weight. After mid-term evaluation, participants were taught to use the elastic band (Thera-band) held at shoulder width as resistance. To facilitate a better direction of resistance, the position of the extension exercise had been modified to elbow-prone position. The position of flexion exercise was unchanged (Fig. 4c and 5c).

A target level of exertion needed to be achieved in exercise. During week 4 to 6, target level of exertion was set at 4, 5, 6 of 10 in the Borg scale respectively, with 0 meaning ‘rest’ and 10 meaning ‘maximal effort’. The intensity of exercise was controlled by the tightness of the elastic band, adjusted by the
participants. Participants should perform the exercise without elastic band if they had already achieved the designated level of exertion with body weight. Frequency and the resting time remained unchanged.

**Recording of the level of difficulty, compliance of exercise programs and the post-exercise effects**

A recording sheet that consists of five questions was used to record the self-reported level of difficulty, exercise compliance and level of post-exercise soreness for all participants (Fig. 6). Comparison of these data between two exercise programs was conducted to the reveal the safety and practical issues specific to the execution of the exercises.

**Statistical Analysis**

Intra-class correlation coefficient (ICC) was used to assess the reliability of the mean values of EMG amplitudes, torque production and muscle CSA. SPSS statistical analysis software (Version 23.0, IBM) was used for data analysis. Two-way repeated measure analysis of variance (ANOVA) was used to analyze the within and between groups comparisons of outcome measures, as well as the group x time interaction. Pearson's correlation coefficient was used to determine the correlation between EMG amplitude and torque production during maximal isokinetic flexion and extension for evaluation of the changes in the neuromuscular efficiency. The level of significance was set as 0.05.

**Results**

All outcome measures reliability met the ICC criteria (p > 0.05) (Table 1). One participant from VSE group dropped out from the study due to a development of neck pain in other activities. For the 29 participants who completed the program, exercise compliance levels were 0.829 and 0.826 in VSE and IE group respectively. A comparable level of compliance was found between groups (p > 0.05).

**Baseline assessments**

Table 2 shows the baseline data, including demographic data, results in assessments and comparison of data between VSE and IE group. There were no significant differences in all data compared except EMG amplitude of left ES at MVC (p = 0.041).

**EMG activity of the neck flexors and extensors during isokinetic assessment**

Figure 7 shows EMG changes after exercise in VSE and IE group. For both SCM and CES of bilateral sides, both groups showed a significant increase after the exercise intervention (VSE: right SCM: p < 0.001, left SCM: p < 0.001, right CES: p = 0.007, left CES: p = 0.014; IE: right SCM: p < 0.001, left SCM: p < 0.001, right CES: p < 0.001, left CES: p = 0.014).
0.001, right CES: \( p < 0.001 \), left CES: \( p = 0.001 \). However, no significant between-group differences were observed in both muscles \( (p > 0.05) \).

The extent of increase in EMG amplitudes of flexor was higher than that of extensor. In VSE group, the increase in EMG amplitudes of SCM (163–175% MVC) was nearly six-fold of that in ES (31–32% MVC). In IE group, the increase in EMG amplitudes of SCM (213–262% MVC) was around three-fold of that in CES (59–63% MVC).

**Torque performance of the neck flexors and extensors during isokinetic assessment**

Figure 8 shows the pre-post torque performances (Nm) changes of flexion and extension phases in VSE and IE group. Both groups had significant increase in torque performances in both phases after exercise (VSE: flexion: \( p = 0.013 \), extension: \( p = 0.007 \); IE: flexion: \( p = 0.037 \), extension: \( p = 0.002 \)). No significant differences were identified between groups \( (p > 0.05) \).

**Cross-sectional area of the deep neck flexors and extensors assessment using ultrasonography**

Figure 9 shows the pre-post exercise CSA of bilateral LC and SC changes in VSE and IE group. Both exercise groups showed significant increase of muscle size in both LC and SC after exercise (VSE: right LC: \( p = 0.001 \), left LC: \( p < 0.001 \), right SC: \( p = 0.004 \), left SC: \( p < 0.001 \); IE: right LC: \( p < 0.001 \), left LC: \( p < 0.001 \), right SC: \( p = 0.002 \), left SC: \( p < 0.001 \)). However, there were no significant differences between VSE and IE group.

**Correlation between EMG and torque performance of the neck flexors and extensors**

Figure 10 shows the correlation between flexion torque and SCM EMG amplitude. Both groups showed a decrease in strength of correlation after exercise. Statistically significant correlation was only found in baseline measurements of the IE group \( (p = 0.041) \).

Figure 11 shows the correlation between extension torque and CES EMG amplitude. Both groups showed an increase in correlation after exercise. VSE group (0.515) showed a greater increase in correlation compared to IE group (0.164). Statistically significant correlation was only found in post exercise measurements of VSE group \( (p = 0.018) \).

**Level of difficulty, compliance of exercise programs and the post-exercise effects**

Table 3 shows the comparison of self-reported level of exercise difficulty and post-exercise soreness between VSE group and IE group. Using numeric rating scale, the VSE group and IE group rated a
difficulty of 3 (range = 0–6) and 3.53 (range 1–7) in the first 3 weeks. After progression was implemented by the end of 3rd week, the VSE group and IE group rated a difficulty of 5.64 (range = 0–8) and 5.26 (range = 3–7) respectively. There were no significant between-group differences on the difficulty level of the exercises at first 3 weeks and subsequent 3 weeks. Five in 14 participants (35.7%) in the VSE group and 3 in 15 participants (20%) in the IE group reported post-treatment soreness. No significant differences were observed between groups. There were no detrimental responses or complaints about difficulty by the participants.

Discussion

This study aims to explore the effect of neck VSE compared to IE that were more commonly used in neck training and rehabilitation, and to investigate the safety and level of acceptance of the VSE program, for its potential application in managing individuals with neck pain.

The present results showed remarkable improvements in the muscle functions and performance in both exercise groups, substantiated by the significant increase in EMG amplitude of SCM and CES, CSA of LC and SC, and torque production. There were no statistically significant differences between groups in terms of the magnitude of improvement.

EMG activity during isokinetic assessment

The surface EMG amplitude of SCM and CES increased significantly in both groups after the programs. The percentage increase in SCM EMG amplitude was greater than that in CES for both groups. It remains difficult to directly compare our findings to previous studies because research studying exercise induced changes in EMG of neck muscles during isokinetic testing was limited. It was found that EMG amplitude of the neck flexors and extensors increased linearly with increased torque production in the isometric contraction in corresponding direction [15]. The results were in agreement with the force increase found in the isokinetic muscle testing in our study. Therefore, an increase in neck surface EMG amplitude might correspond to increased force produced by the respective muscle.

Torque performance during isokinetic assessment

The torque produced in isokinetic testing increased after exercise in both groups. The 20% and 25% increase in isokinetic strength in flexion and extension respectively after our 6-week IE program were comparable to the results of previous studies. A 5-week neck strengthening program for rugby players improved isometric neck strength by 18% and 21% in flexion and extension [16]. In another study, an 8-week lateral neck flexion IE program demonstrated a significant 9% and 20% increase in isokinetic neck strength at the fourth and eighth week respectively [17]. When comparing the results, the optimal time of neck IE program remains inconclusive, as the ways of performing the exercises and the targeted neck movement varied.
Limited studies investigated the effects of neck VSE. However, isotonic neck exercises, which shared the similar nature to VSE except for the standardised execution speed, were found to be effective for improvements in neck muscle strength. Conley et al. [18] found a 34% improvement on neck strength in healthy participants when isotonic neck extension exercises were added to a 12-week general strengthening program while the 12-week general strengthening exercise showed no improvement on neck strength. In a study by Mansell et al.[19], an 8-week isotonic neck exercise program for soccer players showed a 15% and 22% improvement in isometric flexion and extension strength respectively. The improvements were comparable to the extent of increase in isokinetic strength in flexion (23%) and extension (16%) in VSE group revealed in our study. The additional strength gains from study by Conley et al. might imply the necessity to evaluate the potential gains from VSE in a longer intervention period.

**Cross-sectional area assessment of the deep neck muscles**

CSA of deep neck extensors and flexors improved after exercise in both groups. For IE group, the CSA increased by 20–26% for LC, and 8–9% for SC. An 11% improvement in CSA of LC was found in neck pain participants who completed an 8-week neck flexion IE program [20]. The hypertrophic effect was only half of ours. With similar exercise program, it was deduced that the hypertrophic effect on LC might be smaller in neck pain participants. Pain might limit exercise intensity and quality of movement, reducing the strengthening effect. For deep neck extensors, our study was the first to examine the changes in CSA of SC by IE. The smaller hypertrophic effect on deep neck extensors with similar exercise intensity needed further investigation.

For VSE group, the CSA increased by 25–26% for LC, and 8–14% for SC. In the absence of previous data from asymptomatic group, our findings showed a two-fold increase in CSA of LC compared to the 12% improvement in neck pain participants after a 10-week isotonic neck flexion exercise program [21]. The differences in exercise effect on CSA of LC might indicate that VSE results in a more profound hypertrophy effect on deep neck flexors compared to isotonic exercise. However, such discrepancy could also be explained by the different responses towards exercise between participants with and without neck pain. For the CSA of SC, a 12-week isotonic neck extension exercise program showed a 24% increase in CSA of SC in health college students [18]. It was interesting that the muscle size continued to improve after 6th week of the program. Combined with the findings on the torque, it might be deduced a potential benefit in long term VSE program.

The CSA of LC might be correlated to the neck function and pain. Previous study showed that CSA of LC was smaller in neck pain participants [22]. The muscle size reduction might be attributed to muscle inhibition due to the changes in cervical spine motor control. On the other hand, the small muscle size could be the cause of neck pain with insufficient active stabilization. The correlation between CSA of SC and neck pain remained controversial. Previous study found an increased CSA of SC in neck pain adolescents [23]. In contrast, Fernández-De-Las-Peñas et al. [24] found a reduced deep neck extensor size in women with chronic neck pain. It should be noted that deep neck muscle size might not be the best predictor of neck pain and function [25]. More attention should be put on neck muscle activation pattern and muscle strength instead.
Correlation between EMG amplitude of the superficial neck flexor and extensor, and torque performance during isokinetic assessment

From the result of torque, EMG (% of MVC) and muscle CSA, there was a significant within group difference but not between-group difference. However, this might not indicate that there were no differences in effects between two exercises. Neuromuscular control of the muscles was revealed by the correlation between the EMG activity and functions of the corresponding muscles. However, in this study, it was not possible to use intramuscular EMG to record the deep neck muscle activity during movement testing. We adopted an explorative approach to analyze the neuromuscular efficiency expressed as the strength of the correlation between torque production and the EMG amplitude of corresponding muscle. Superficial neck muscles contribute in neck movement force generation while deep neck muscles act as primary neck stabilizers. However, if the deep muscles could not effectively contribute in stabilization, the superficial muscles might compensate by maximizing their dual role for both neck movement force generation and segmental stabilization [3]. If there was a same peak superficial muscle EMG amplitude between two people but one needed compensation by superficial muscles, the force generation would be less effective. The association between torque production and peak EMG amplitude would become lower, implying a poorer neuromuscular efficiency.

Statistically significant correlation between the CES activity and neck extension torque was only found in VSE group but not in IE group. Combining the findings in investigation of the muscle size that both groups showed a similar muscle hypertrophy in SC, it could be deduced that VSE might be more effective in promoting the efficiency of the CES in torque generation and in training of deep neck extensors. Participants from VSE group might be more adapted to activate their deep neck extensors during dynamic movement while those from IE group were less accustomed due to the static nature of their exercise. Therefore, in isokinetic torque productions in IE group, SC were less efficient in segmental stabilization and the CES had to contribute in stabilization. The torque producing efficiency of the CES had been reduced as a result which was shown by the less significant correlation.

In contrary, correlations between SCM activity and neck flexion torque post-intervention were insignificant in both groups, despite the significant muscle size increase of LC in both groups. This manifestation could possibly be explained by the dramatic increase in SCM activities after intervention. A nearly three-fold increase was found in SCM activity, which was much higher than that in CES (around 15%). On the other hand, the muscle size of LC only showed a 25% increase. The extent of increase in LC strength might fail to catch up with the extremely high demand for postural stability related to the increased SCM activity and strength. Therefore, SCM might have contributed to postural stability as compensation and reduced the torque producing efficiency. By reviewing our exercise program design, we suspected that the exercises for neck flexion might be too demanding though all participants were able to perform the exercise safely. The increase in CSA of LC (20–26%) was two-fold of that in SC (8–14%). It might imply that the flexion exercise intensity was much higher than that of extension in both groups, and it might
even exceed the maximum loading of LC. Participants were required to maintain chin tucked during flexion exercise. It might place a huge loading to the LC. The gravity and the resistance from the elastic bands further load the LC. Hence, participants might adopt a wrong muscle activation pattern during exercise.

**Safety and comfort of the exercises**

All the participants performed the exercises safely. Attempts were made to protect the participant's neck. Participants were required to tuck their chin to reduce shearing force on the cervical spine. No detrimental responses or complaints about difficulty were reported by the participants. Difficulty of the exercises was reported from 0–8/10. There were only a few reports of temporary post-exercises soreness from both groups. Previous study also found no adverse events in an isotonic neck exercise plus infrared irradiation program for neck pain participants [26]. This indicates that VSE had been generally safe.

**Limitations**

There were several limitations in the study. The sample size was small with only 29 participants. It resulted in a reduced statistical power and difficulty in obtaining a significant between-group difference. Besides, the exercise program was in short duration. A previous study had shown that IE had strengthening effect on muscle even after 3 years [27]. The long-term effect of VSE is yet to be investigated. Asymptomatic participants were recruited. Exercise effect in neck pain patients might be different due to different muscle activation patterns during neck movements [3].

The participants were relatively young and 62.1% exercise regularly. This might explain the larger deep neck muscle sizes at baseline compared with previous studies. The means of CSA of bilateral LC of our participants were slightly larger (0.97 cm² compared to 0.85–0.87 cm²). The differences are even greater for SC (2.39–2.41 cm² compared to 1.70–1.73 cm²) [28, 29]. Therefore, our results might not be generalizable to older and more sedentary populations with smaller muscle size.

**Clinical implication and future study**

Findings of the present study showed that VSE were comparable with IE in improving neck function and performance. VSE might be superior to IE in promoting efficiency of superficial neck muscle in torque generation. It had been shown by various studies that IE were effective in improving neck function and reducing neck pain intensity, and hence they were prescribed to participants with neck pain [6, 30]. With the findings from this study, VSE might serve as an alternative to IE in neck training and rehabilitation. Future studies are recommended to investigate the immediate and long-term effects of VSE on recovery of patients with neck dysfunction. In addition, other parameters, for example, the composition and type of muscle fiber of neck should be examined to better reveal the physiological mechanisms underlying the changes induced by VSE in neck pain participants and substantiate its clinical efficiency.

**Conclusions**
Participants in both groups showed significant increase in EMG amplitude in SCM and CES, muscle size of LC and SC, and torque production in flexion and extension. Difference in increase between both groups were not statistically significant. Significant correlation was found between extension torque and CES EMG amplitude after exercise in VSE group, which may imply an improvement in neuromuscular efficiency. VSE may be an alternative to IE in neck training and rehabilitation. Effects on neck pain participants may be a possible direction for further research.

Abbreviations

ANOVA: Analysis of variance; BPM: Beats per minute; CES: Cervical erector spinae; CSA: Cross-sectional area; EMG: Electromyography; ICC: Intra-class Correlation Coefficient; IE: Isometric exercise; LC: Longus Colli; MVC: Maximal Voluntary Contraction; SC: Semispinalis Capitis; SCM: Sternocleidomastoid; SENIAM: Surface EMG for non-invasive assessment of muscles; VSE: Velocity specific exercise

Declarations

Ethics approval and consents to participate

Ethical approval from the Ethics Committee of the Hong Kong Polytechnic University was obtained for this study. Each author certifies that all investigations were conducted in conformity with ethical principles. Written informed consent was obtained from all participants included in this study.

Consent to publish

All authors confirmed that this is the original work and agreed for publication in BMC Musculoskeletal Disorders.

Availability of data and materials

The datasets supporting the conclusions of this article are included within the article. The raw data can be requested from the corresponding author.

Competing interests

The authors declared that they have no competing interests.

Funding

This study was not supported by any research fund.
Author’s contributions

ST, KC, PH, JK, DT and HT formulated the research topic and study design. KC, PH, JK, DT and HT participated in the recruitment, data collection and analysis. ST, KC, PH, JK, DT and HT prepared, revised and approved the manuscript.

Acknowledgements

The authors would like to thank the participants who had joined this research project on the voluntary basis.

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Tables

Due to technical limitations, table 1, table 2 and table 3 are only available as a download in the Supplemental Files section.

Figures
30 subjects (21M, 9F) were recruited

Eligibility screening → Subjects were excluded (n=0)

Baseline Assessment (USG, EMG and Torque) (week 0)

Randomization & Teaching of exercise

VSE Group (10M, 5F)    IE Group (11M, 4F)

Exercise Intervention (Week 1 to 3)

Mid-term Evaluation & Progression of Exercise (end of week 3)

Exercise Intervention (Week 4 to 6)
* one male subject from VSE group dropped out due to pain induced from other activities

Reassessment (20M, 9F) (End of week 6)

Figure 1

Study design.
Figure 2

Isokinetic assessment of the neck flexors and extensors at velocity of 30 degrees/second with synchronized recording of 3D cervical spine motion and electromyography.

Figure 3

Measurement of the cross-sectional area of longus colli and semispinalis capitis.
Figure 4

Velocity specific exercise during week 1-3; and b. during week 4-6 with progression using elastic band.
Figure 5

Isometric exercise during week 1-3; and b. during week 4-6 with progression using elastic band.
Name: ____________________  Sex: ______  Age: ______

Type of exercise: A. Velocity-specific exercise (VSE)  /  B. Isometric exercise (IE)

On a scale of 0-10, please rate the level of difficulty of the exercise in the first 3 weeks (i.e. week 1-3):
0  1  2  3  4  5  6  7  8  9  10

In a scale of 0-10, please rate the difficulty of the exercise in the last 3 weeks (i.e. week 4-6):
0  1  2  3  4  5  6  7  8  9  10

Did you experience any post-exercise soreness after practicing your neck exercise program?
A. Yes  B. No

What difficulties have you encountered during the exercise? (list the difficulties or problems you in the box below):

Have you skipped any of the exercise sessions during week 1-3? If yes, how many sessions have you skipped in total?
A. No  B. Yes, I skipped a total _______ sessions during week 1-3 of the program

Have you skipped any of the exercise sessions during week 4-6? If yes, how many sessions have you skipped in total?
A. No  B. Yes, I skipped a total _______ sessions during week 4-6 of the program

Figure 6

Recording of self-reported level of difficulty and post-exercise soreness, and exercise compliance.
Figure 7

Comparisons of mean value of EMG amplitude of Sternocleidomastoid during neck flexion phase and cervical erector spinae during neck extension phase of the isokinetic test between velocity-specific exercise program and isometric exercise program, pre- and post-exercise intervention. * indicates significant pre-post changes (p<0.05).
Figure 8

Comparisons of mean value of torque produced in flexion and extension phase during the isokinetic test between velocity specific exercise group and isometric exercise group, pre- and post-exercise intervention. * indicates significant pre-post changes (p<0.05).
Figure 9

Comparisons of mean value of cross-sectional area of bilateral longus colli and semispinalis capitis (SC) between velocity specific exercise group and isometric exercise group, pre and post exercise intervention. * indicates significant pre-post changes (p<0.05).
Figure 10

Correlation between flexion torque and sternocleidomastoid EMG amplitude in velocity specific exercise group and isometric exercise group, pre- and post-exercise intervention. * indicates significant correlation (p<0.05).
Figure 11

Correlation between extension torque and cervical erector spinae EMG amplitude in velocity specific exercise group and isometric exercise group, pre- and post-exercise intervention. * indicates significant pre-post changes (p<0.05).

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- CONSORTchecklist.pdf
- Table1.pdf
- Table2.pdf
- Table3.pdf