

Impact of Threshold Inspiratory Muscle Training on Diaphragmatic Function and Ventilatory Efficiency in Individuals with Forward Head Posture

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Received: 16th Aug, 2026; Revised: 08th Sep 2026; Accepted: 12th Sep, 2026; Available Online: 22th Sep, 2026

ABSTRACT

Background: Prolonged use of media devices has been strongly linked to changes in posture, with forward head posture (FHP) being the most common presentation. This postural alteration can influence respiratory mechanics and diaphragmatic function.

Objectives: This study explored whether adding threshold inspiratory muscle training (IMT) to a conventional rehabilitation program could improve ventilatory function, diaphragmatic excursion, and craniocervical angle in young women with FHP.

Methods: Sixty females (18–25 years) with FHP were randomly assigned to two groups. Group A received interval IMT (50–70% 1RM, three sessions/week for 12 weeks) combined with a conventional postural corrective program, while Group B received a conventional program alone. Outcomes included measurements of the craniocervical angle (CCA) using a digital camera. Spirometry indices (FVC, FEV1, FEV1/FVC, PEFR), diaphragmatic excursion by using M model Ultrasonography (LOG IQ E10S), and chest expansion.

Results: Both groups improved significantly in all measures post-intervention ($p < 0.05$). However, IMT Group showed better gains in FEV1 (+3.73%, $p = 0.002$), FEV1/FVC (+3.86%, $p = 0.0001$), PEFR (+8.20%, $p = 0.0001$), diaphragmatic excursion (+0.73 cm, $p = 0.0001$), and lower-lobe chest expansion (+0.76 cm, $p = 0.0001$).

Conclusion: Incorporating IMT into standard corrective exercises enhances diaphragmatic function and ventilatory efficiency, while also improving cervical posture. These findings suggest that IMT can be a valuable addition to rehabilitation programs for individuals with FHP.

Keywords: Forward head posture; Craniocervical angle; Ventilatory function; Diaphragmatic excursion; Peak expiratory flow rate.

How to cite this article: Youssef H.A, Badr N.M.H, Abd El-Monaem H.A, Ahmed K.T, Shaaban M.A, Alghitany S.I.A, Impact of Threshold Inspiratory Muscle Training on Diaphragmatic Function and Ventilatory Efficiency in Individuals with Forward Head Posture. 2026;16(84s): 1617-1623; DOI: 10.25258/ijddt.16.84s.163

Source of support: None

Conflict of interest: None

INTRODUCTION

Forward head posture (FHP) is a prevalent musculoskeletal disorder linked to prolonged use of modern digital technologies. Sustained engagement with smartphones and computers imposes continuous static loading on the cervical spine, leading to hyperextension of the upper cervical vertebrae and anterior displacement of the lower cervical segments 1, 2. Global smartphone ownership is estimated at 90%, representing over 7.2 billion users 3. Meanwhile, in Egypt alone, active mobile subscriptions surpassed 84 million as of 2024, according to the Ministry of Communications and Information Technology (MCIT) 4. This pervasive device usage highlights the increasing relevance of postural dysfunction, particularly among

adolescents and young adults 5-8. FHP is not merely a postural deviation; it is functionally consequential. Altered cervical alignment has been shown to affect motor control, chest wall mechanics, and diaphragmatic function 9. Individuals with FHP typically exhibit a reduced craniocervical angle (CCA), diminished chest expansion, impaired diaphragmatic excursion, and greater reliance on accessory respiratory muscles such as the sternocleidomastoid 10. These biomechanical alterations increase the work of breathing, restrict thoracoabdominal mobility, and compromise ventilatory efficiency 11, 12. Notably, even short-term adoption of FHP can attenuate phrenic nerve activity, thereby reducing diaphragmatic contractility and lung volumes 9, 13. Given that respiration

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involves intricate interactions between mechanical and non-mechanical factors, including age, lifestyle, disease, and posture, postural deviations like FHP can significantly disrupt normal breathing patterns 14.

Inspiratory muscle training (IMT) has been proposed as a targeted intervention to mitigate the respiratory dysfunctions associated with FHP. Through the application of threshold loading, IMT promotes inspiratory muscle strength and endurance, improves diaphragmatic mobility, and augments ventilatory capacity 15. Threshold IMT devices are widely regarded as simple, cost-effective, and clinically validated tools for these purposes 16. Nevertheless, despite accumulating evidence supporting the efficacy of IMT in pulmonary rehabilitation, its specific effects on diaphragmatic function and postural correction in individuals with FHP remain insufficiently investigated. Accordingly, we aimed to examine the effects of threshold IMT on respiratory function, diaphragmatic excursion, and CCA in young women with FHP.

MATERIALS AND METHODS

Study design and Participants

This randomized controlled trial employed a parallel-group design and was carried out in the outpatient clinics of the Faculty of Physical Therapy at Misr University for Science and Technology. Sixty female volunteers aged 18–25 years,

all diagnosed with FHP, defined as a CCA between 30° and 50°, were recruited from the same institution. Participants also met the criterion of having a BMI of 24.9–29.9 kg/m². Exclusion criteria comprised neurological or neuromuscular conditions affecting respiratory muscles (e.g., cervical disc bulge, muscular dystrophy), prior cervical spine surgery, musculoskeletal deformities such as scoliosis or kyphoscoliosis, and a history of chronic respiratory disease. Block randomization was used to allocate participants into two equal groups (n = 30 per group). Specifically, participants were divided into blocks of six, and within each block, individuals were randomly allocated to either the experimental or control group (Figure 1).

The Research Ethics Committee of the Faculty of Physical Therapy, Cairo University, Egypt, authorized the study (P.T. REC/012/003457) and was prospectively registered on ClinicalTrials.gov (ID: NCT06571578). All procedures followed the Declaration of Helsinki, with all participants signing informed consent after a thorough explanation of the study's purpose, potential benefits, and their right to withdraw at any time without penalty.

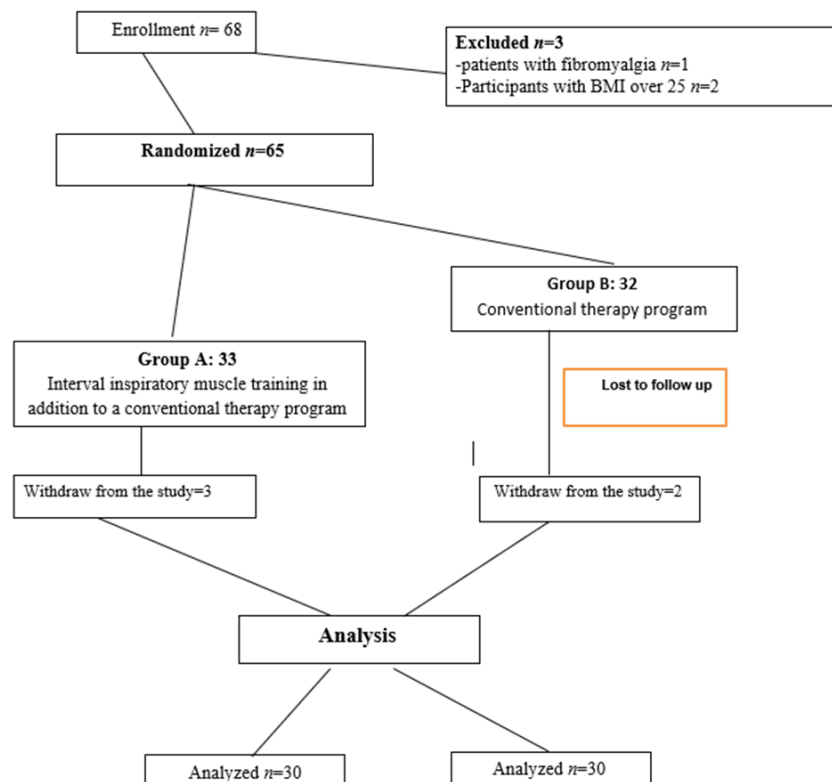


Figure 1. Study flowchart.

Procedures

Participants were assigned at random to two equal groups (n = 30 per group). The experimental group (Group A)

received threshold IMT and a conventional FHP exercise program, whereas the control group (Group B) performed

only the conventional program. Both groups trained three times weekly for 12 weeks.

In Group A, IMT was delivered using the Threshold Inspiratory Muscle Trainer (Model HS 730-010, UK). Participants inhaled through an individual mouthpiece while wearing a nasal clip to prevent air leakage. The device employs a spring-loaded valve that opens only when inspiratory effort exceeds a predetermined threshold, thereby providing consistent resistance independent of airflow rate. The training protocol followed a high-intensity interval training model 17. Intensity was progressively increased from 50% of one-repetition maximum (1RM) during weeks 1–2, to 60% during weeks 3–4, and maintained at 70% for weeks 5–12. Each session comprised three cycles of 2 minutes of high-intensity breathing (50–70% 1RM) interspersed with 2 minutes of active recovery at low intensity (20% 1RM), with a 2-minute rest between cycles 18.

The conventional exercise program for FHP comprised three components, performed three times weekly for 12 weeks: (I) Stretching exercises for A) For the scalene and levator scapulae muscles: Participants sat on a chair, tilted their chin downward toward one shoulder, and applied gentle overpressure with the ipsilateral hand on the head, maintaining the stretch for 30–60 seconds. B) For the upper fibers of the trapezius: Participants side-bent the neck by bringing the ear toward the shoulder and used the ipsilateral hand to deepen the stretch, holding the position for 30–60 seconds 19; (II) Cervical isometric exercises: Performed in a seated position, participants applied manual resistance with their hands against the forehead, occiput, and sides of the head to isometrically engage cervical flexors, extensors, rotators, and lateral flexors. Each contraction lasted 10 seconds, followed by 15 seconds of rest, repeated 10–15 times per direction 20; (III) The postural correction exercise: Participants began by gently rolling the pelvis forward to achieve a neutral, upright sitting posture, then retracted and depressed the scapulae, and performed an occipital lift to align the head over the trunk. Additionally, for suboccipital muscle stretching, participants sat upright, gently tucked their chin toward their neck (cranio-cervical flexion), and applied slight downward pressure with both hands on the top of their head, holding the position for 10 seconds. This maneuver was repeated five times per session 19.

Outcome measures

Primary and secondary outcome measures were assessed at baseline and after 12 weeks. CCA was evaluated from lateral-view photographs. Participants stood in a standardized position, with their feet shoulder-width apart, their arms relaxed at their sides, and their gaze fixed on a target at eye level. A digital camera equipped with a triple rear camera system (50 MP wide-angle, 8 MP ultra-wide, and 5 MP macro lenses) was mounted on a tripod at the height of the seventh cervical vertebra (C7) and positioned 1.5 meters laterally from the participant's right foot 21. Images were analyzed using Kinovea software (version Kinovea-2023.1.2.exe) to determine the CCA, defined as the angle formed between a horizontal line passing through the C7 spinous process and a line connecting C7 to the

midpoint of the tragus of the ear 22. Based on established criteria, a CCA greater than 50° was classified as normal posture, 30°–50° as mild to moderate FHP, and below 30° as severe FHP 23.

Ventilatory Function Assessment: Pulmonary function was evaluated by a digital spirometer (CONTEC SP10, China) to measure forced vital capacity (FVC), forced expiratory volume in one second (FEV₁), the FEV₁/FVC ratio, and peak expiratory flow rate (PEFR). Before testing, the device was calibrated according to the manufacturer's guidelines. Participant identification was verified, and demographic and anthropometric data, including age, sex, race, height (measured barefoot), and weight, were recorded to enable calculation of predicted values. During testing, participants sat upright with feet flat on the floor, wore loose-fitting clothing to avoid restricting thoracic expansion, and were instructed to refrain from engaging accessory or abdominal muscles during maneuvers. Results were expressed as percentages of predicted values 24.

Diaphragmatic Excursion Measurement (cm): Diaphragmatic excursion was assessed via M-mode ultrasonography using a LOGIQ E10S system. A trained radiologist performed all scans, focusing on the right hemidiaphragm due to the superior acoustic window and reduced interference from gastric and splenic structures compared to the left side. The transducer was positioned on the anterior subcostal region, midway between the anterior axillary and midclavicular lines. Participants performed a maximal inhalation followed by a complete exhalation, and two M-mode sweeps were captured, one at peak inspiration and one at end-expiration, to quantify diaphragmatic displacement in centimeters 25.

Chest Expansion Assessment: Chest expansion was measured at three anatomical levels using a flexible tape measure: (1) upper thorax at the second intercostal space, (2) mid-thorax at the fourth intercostal space (nipple line), and (3) lower thorax at the xiphoid process. Participants first exhaled fully, then inhaled maximally; the difference in circumference between these two states represented chest expansion at each level. Three trials were conducted at each site, and the mean value was utilized for analysis 26.

Statistical analysis

Statistical analyses were performed using SPSS (v25, SPSS, Inc., Chicago, IL). An independent-samples t-test was used to determine baseline comparability between groups with respect to demographic characteristics (age, height, weight, and BMI). To evaluate the effects of the intervention over time and between groups, a mixed-design 2 × 2 multivariate analysis of variance (MANOVA) was conducted. The between-subjects factor was group allocation (experimental vs. control), and the within-subjects factor was time (pre- vs. post-intervention). The dependent variables included CCA, FVC, FEV₁/FVC ratio, PEFR, diaphragmatic excursion, and chest expansion.

Results

The participants in both groups revealed no significant differences in age, height, weight, or BMI at baseline or post-intervention ($p > 0.05$; Table 1).

Table 1. Participants' general characteristics

Items	Subjects general characteristics			
	Age (Year)	Weight (kg)	Height (cm)	BMI (kg/m ²)
Group A (n=30)	22.23 ±0.81	67.57 ±3.85	162.07 ±4.51	25.71 ±0.90
Group B (n=30)	22.30 ±1.02	66.83 ±4.90	160.37 ±3.82	25.95 ±0.79
t-value	0.279	0.644	1.574	1.073
P-value	0.781	0.522	0.121	0.288
Significance	NS	NS	NS	NS

Data are expressed as Mean ±Standard Deviation (SD); P-value: Probability value; NS: Non-significant

At baseline, there were no significant differences between the two groups in CCA, FVC, FEV₁, FEV₁/FVC ratio, PEFR, diaphragmatic excursion, or chest expansion (all $p > 0.05$). Following the 12-week intervention, both groups demonstrated significant within-group improvements in all

measured parameters ($p < 0.05$; Table 2). However, between-group comparisons revealed that Group A exhibited significantly greater improvements than Group B in FEV₁, FEV₁/FVC ratio, PEFR, diaphragmatic excursion, and lower lobe chest expansion ($p < 0.05$).

Table 2. Within-group comparison regarding craniocervical angles, ventilatory function, diaphragmatic excursion, and chest expansion

		Group A	Group B	F-test Value	P-value
		$\bar{x} \pm SD$	$\bar{x} \pm SD$		
craniocervical angle (CCA) (degree)	Pre- intervention	38.75 ±2.84	39.53 ±2.24	1.533	0.218
	Post-intervention	47.21 ±2.12	47.29 ±2.48	0.016	0.899
	%of change	21.83%	19.63%		
	Within-group comparison	0.0001*	0.0001*		
Forced vital capacity (FVC) (%)	Pre- intervention	61.30 ±3.78	62.00 ±4.76	0.511	0.476
	Post-intervention	69.53 ±2.66	69.06 ±3.65	0.227	0.634
	%of change	13.43%	11.39%		
	Within-group comparison	0.0001*	0.0001*		
Forced expiratory volume in the first second (FEV ₁) (%)	Pre- intervention	69.00 ±4.11	68.93 ±5.45	0.003	0.954
	Post-intervention	77.13 ±3.32	73.40 ±4.68	10.505	0.002*
	%of change	11.87%	6.48%		
	Within-group comparison	0.0001*	0.0001*		
FEV ₁ /FVC ratio (%)	Pre- intervention	111.93 ±2.79	111.93 ±1.20	0.000	1.000
	Post-intervention	106.80 ±3.95	110.66 ±1.82	31.834	0.0001*
	%of change	4.58%	1.13%		
	Within-group comparison	0.0001*	0.047*		
Peak expiratory flow rate (PEFR) (%)	Pre- intervention	70.56 ±9.96	69.26 ±7.14	0.512	0.522
	Post-intervention	87.26 ±5.86	79.06 ±7.84	16.379	0.0001*
	%of change	23.67%	14.15%		
	Within-group comparison	0.0001*	0.0001*		
Diaphragmatic excursion (cm)	Pre- intervention	3.81 ±0.53	3.75 ±0.35	0.202	0.654
	Post-intervention	4.84 ±0.65	4.11 ±0.53	28.775	0.0001*
	%of change	27.03%	9.60%		
	Within-group comparison	0.0001*	0.009*		
Upper lobe chest expansion test (cm)	Pre- intervention	3.77 ±0.56	3.80 ±0.66	0.639	0.426
	Post-intervention	4.97 ±0.85	4.56 ±0.50	1.734	0.189
	%of change	31.83%	20.00%		
	Within-group comparison	0.0001*	0.0001*		
Middle lobe chest expansion test (cm)	Pre- intervention	4.03 ±0.31	3.90 ±0.71	0.760	0.385
	Post-intervention	5.16 ±0.59	4.88 ±0.66	3.434	0.066
	%of change	28.04%	25.13%		
	Within-group comparison	0.0001*	0.0001*		
Lower lobe chest expansion test (cm)	Pre- intervention	4.46 ±0.50	4.43 ±0.62	0.051	0.821
	Post-intervention	5.96 ±0.58	5.20 ±0.55	27.200	0.0001*
	%of change	33.63%	17.38%		
	Within-group comparison	0.0001*	0.0001*		

$\bar{x}$: Mean; SD: Standard deviation; *: Significant ($P < 0.05$); P-value: probability value; %: Percentage

DISCUSSION

This study aimed to evaluate the effects of threshold IMT on respiratory function, diaphragmatic excursion, and CCA in young women with FHP. Results demonstrated a significant improvement in CCA in both groups, consistent with prior evidence indicating that postural corrective exercises effectively increase CCA and alleviate FHP 27-30. Ventilatory function, assessed via FVC, FEV₁, PEF, and FEV₁/FVC ratio, also improved in both groups following the intervention. However, Group A exhibited significantly greater gains in FEV₁, PEF, and FEV₁/FVC compared to Group B, which received only conventional exercises. These findings align with Parida et al.³¹, who reported that combining breathing exercises with postural correction yields superior peak expiratory flow rate improvements among individuals with FHP compared to postural correction alone. Similarly, Yu et al.³² observed that integrating cervical stabilization with breathing exercises significantly enhanced multiple pulmonary function indices, including FVC, FEV₁, PEF, and FVC/VC max%, in participants with FHP. Furthermore, Mohammed et al.³³ documented significant improvements in FEV₁%, FEV₁/FVC, and FVC% following IMT in occupational COPD patients, underscoring the broader applicability of IMT in enhancing respiratory mechanics.

The second key finding of this study was the improvement in diaphragmatic excursion, which was observed in both groups but was significantly greater in Group A. This aligns with Dareh-deh et al.³⁴, who reported increased diaphragmatic electromyographic (EMG) activity after an 8-week multimodal program incorporating breathing exercises, resistance training, and stretching. Threshold IMT enhances respiratory muscle strength (RMS) by imposing a progressive inspiratory load that stimulates both the diaphragm and accessory inspiratory muscles³⁵. This mechanical stimulus may promote structural and functional adaptations, including diaphragm hypertrophy, potentially facilitated by the high oxidative and glycolytic capacity of types I and II fibers in the external intercostal muscles³⁶. Supporting this, Mansfield et al. demonstrated that threshold IMT significantly increases maximal inspiratory pressure and thoracoabdominal tidal volume during exercise in healthy older adults, thereby reducing mechanical constraints on the chest wall and augmenting diaphragmatic power³⁷. Chest wall expansion, particularly at the lower rib cage, is influenced by multiple factors, including lung and chest wall elasticity, inspiratory muscle strength, and the execution of breathing exercises that emphasize thoracic mobility. Prior research has established a positive correlation between inspiratory muscle strength and chest expansion in healthy individuals³⁸, which helps explain the significantly greater improvement in lower lobe chest expansion observed in the IMT group. Collectively, these findings suggest that IMT enhances diaphragmatic excursion by strengthening the primary inspiratory muscles, which in turn facilitates greater caudal displacement of the diaphragm during inspiration. This mechanical action directly increases lower thoracic expansion and contributes to improved lung volumes in FHP individuals.

Our findings highlight the clinical utility of integrating threshold IMT into conventional postural rehabilitation for young women with FHP. Given that FHP is associated with impaired diaphragmatic function, reduced ventilatory efficiency, and altered thoracoabdominal mechanics, IMT provides a targeted, adjunctive strategy to enhance inspiratory muscle strength, increase diaphragmatic excursion, and improve lower chest wall expansion. Clinicians managing individuals with posture-related respiratory compromise, particularly those whose symptoms are exacerbated by prolonged use of digital devices, should consider IMT as an evidence-based complement to standard corrective exercises, concurrently optimizing postural alignment and pulmonary function. This approach may be especially relevant in populations characterized by high levels of sedentary behavior and screen exposure, where musculoskeletal and respiratory dysfunctions frequently coexist.

Despite these promising results, several limitations should be considered. First, the sample was restricted to young adult women, limiting the findings' generalizability to males or older age groups. Second, the 12-week intervention period precluded assessment of long-term adherence and sustained effects, leaving the durability of observed benefits uncertain. Third, only a single threshold IMT device was employed; alternative devices or resistance protocols might produce different physiological responses. Finally, unmeasured psychosocial and lifestyle variables, such as habitual physical activity, sleep quality, and ergonomic practices, were not controlled, and these may have confounded the outcomes. Future studies should address these gaps by examining the long-term efficacy of IMT, its applicability across diverse demographic groups, and the comparative effectiveness of varying IMT modalities and training intensities.

CONCLUSIONS

This study proves that supplementing conventional corrective exercises with threshold IMT leads to significantly greater improvements in pulmonary function, diaphragmatic excursion, and chest wall expansion among young women with FHP. These findings support the integration of IMT as a complementary, evidence-based component in the rehabilitation of FHP to enhance both respiratory and postural outcomes.

Conflicts of interest

None.

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