

Effects of Respiratory-Muscle Exercise on Spinal Curvature

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Design: Randomized controlled study. **Setting:** Laboratory. **Participants:** 26 healthy swimmers randomly assigned to an exercise (n = 13; Ex) or control group (n = 13; Cont). **Intervention:** The Ex group performed respiratory-muscle exercises for 10 min thrice a week for 4 wk. **Context:** Respiratory-muscle exercises are used not only in the rehabilitation of patients with respiratory disease but also in endurance training for athletes. Respiration involves the back and abdominal muscles. These muscles are 1 of the elements responsible for posture control, which is integral to injury prevention and physical performance. However, the effects of respiratory-muscle exercise on posture remain unclear. **Objective:** To examine the potential of respiratory-muscle exercise for improving posture. **Main Outcome Measures:** Spinal curvature, pulmonary function, and trunk-muscle strength were measured for both the groups at baseline and after 4 wk. The data were compared between the Ex and Cont groups with Mann-Whitney *U* test and preintervention and postintervention within groups with a Wilcoxon signed rank-sum test. **Results and Conclusion:** The spinal curvature was significantly different in the Ex group, indicating a decrease in the thoracic (−13.1%, $P < .01$) and lumbar (−17.7%, $P < .05$) angles. The Ex group presented with lower thoracic (−8.6%) and lumbar (−20.9%) angles at postexercise than the Cont group ($P < .05$). With respect to trunk-muscle strength, only trunk-flexion strength significantly increased from pretest to posttest in the Ex group ($P < .05$). For pulmonary function, forced vital capacity and forced expiratory volume in 1.0 s were significantly increased after 4 wk in the Ex group ($P < .05$). The results suggest that respiratory-muscle exercise straightened the spine, leading to good posture control, possibly because of contraction of abdominal muscles.

Keywords: trunk-muscle training, spinal alignment, low back pain

In competitive sports, the spine of young athletes can have excess thoracic kyphosis and lumbar lordosis because it is the conduit for transferring mechanical power between the upper and lower extremities during rapid and forceful movements.¹ Consequently, it is subjected to large 3-dimensional bending moments in flexion, extension, and axial rotation, with concomitantly large compression and shear forces. Under the influence of these forces, athletes have much degeneration of the intervertebral disks,² and the loss of disk height with denaturation is associated with increased spine curvature.¹ Thoracic kyphosis and lumbar lordosis contribute to back pain.³ Much inclined thoracic kyphosis lessens or increases lumbar lordosis. The loss or increase of lumbar lordosis correlates well with the incidence of chronic low back pain.^{4,5} In addition, thoracic kyphosis leads to shoulder pain.³ In swimming, shoulder pain termed swimmer's shoulder⁶ occurs frequently. The major cause of swimmer's shoulder has been thought to be impingement of the subacromial structures.^{6,7} A recent review article identified scapular-motion abnormalities in subjects with

impingement.⁸ Scapular-motion abnormalities result from several factors such as inadequate serratus anterior activation, excess upper trapezius activation, pectoralis minor tightness, posterior capsule tightness, inadequate rotator-cuff activation or partial tearing, pectoralis major tightness, and thoracic kyphosis or flexed posture.⁸ In particular, thoracic hyperkyphosis encumbers motions of the scapulothoracic joint—for example, greater scapular internal rotation and anterior tilt and lesser scapular upward rotation.⁸ Swimming-stroke motions require great range of motion in the shoulder joint. When thoracic hyperkyphosis and decreased motion of the scapulothoracic joint occur, the glenohumeral joint covers the gaps of motion in the swimming stroke. Thus, the glenohumeral joint is used more than it usually would be, leading to swimmer's shoulder. Spinal-alignment control is essential for preventing various injuries. Alignment depends on muscle strength and balance, muscle tightness, and skeletal structure.⁹

The trunk muscles are grouped into 2 categories: global and local stabilizers.¹⁰ The global stabilizers comprise superficial muscles such as the rectus abdominis and longissimus muscles, and the local stabilizers are deep muscles, for example, the transverse abdominal and multifidus muscles.¹⁰ Cholewicki et al¹¹ reported that the

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contraction of local stabilizers is indispensable to trunk stability; that is, the trunk becomes unstable in the case of contraction of global stabilizers alone. The unstable trunk increases stress to the ligament and bone that control the end of motion and cause pain such as back pain.¹²

Exercises for local stabilizers are performed by athletes for injury prevention¹³ and improved sport performance.¹⁴ Alternatively, stabilizing exercises like Pilates^{15,16} and yoga¹⁷ lead to good posture. However, local stabilizing exercises entail certain problems. For beginners attempting the exercise, it is difficult to selectively contract the local stabilizers, and most individuals contract the global stabilizer muscles instead. It can lead to injury during sports activities, so exercises that stimulate local stabilizers selectively and easily need to be developed.

Respiratory-muscle exercises are used in the rehabilitation of chronic obstructive pulmonary disease¹⁸ and endurance exercise for athletes.¹⁹ The muscles comprise the diaphragm, intercostal muscles, and the accessory muscles of respiration.²⁰ The accessory muscles of respiration consist of several of the trunk muscles, including local stabilizers. Therefore, this study focused on exercises for the respiratory muscles, which have the advantage that the load can be accurately set by regulating frequency and depth of breathing. We hypothesized that respiratory-muscle exercises would stimulate the local stabilizers, alter spinal curvature, and straighten postural alignment. This original study is the first to examine the potential of respiratory-muscle exercises for improving postural control in spinal curvature.

Methods

Participants

We recruited 26 healthy swimmers from 2 swim teams. Swimmers who had had severe respiratory dysfunction (eg, asthma or pneumonia) or spinal injury were excluded for the study. Participants were randomly assigned to an exercise or control group (each $n = 13$, 8 males and 5 females; Table 1). No smokers were included; all the participants were under age.

Procedure

Spinal curvature was measured with the SpinalMouse (Idiag Co, Switzerland; Figure 1), an electronic computer-aided measuring device, which measures sagittal-spinal ROM and intersegmental angles in a noninvasive way, a so-called surface-based technique.

This device can measure the angle between the vertebral bodies from C7 to S3, with data corresponding to those obtained from X-rays.²¹ After basic data are obtained for the patient, including height, weight, gender, and age, the SpinalMouse is run paravertebrally along the spinal column from C7 to S3. When manually guided paravertebrally along the spine of a subject, the system records the outline of the skin over the spinal column in the sagittal plane. The local angle or inclination relative to a perpendicular line is given at any position by an internal pendulum connected to a potentiometer. An intelligent recursive algorithm computes information concerning the relative position of the vertebral bodies of the underlying bony spinal column. Raw data of the SpinalMouse measurements are the superficial back length from C7 to S3 and the local angle of each point of this length relative to the plumb line. In this manner, spinal curvature and 17 segments (Th1/2–L5/S1) are evaluated. Based on the measurements, this study defined the total C7–L1 angle as the thoracic kyphosis angle (TH angle) and the total T12–S1 angle as the lumbar lordosis angle (L angle).²¹

Pulmonary function was measured by Autospiro AS-407 (Minato Medical Science Co, Japan) to confirm the effect of respiratory-muscle exercise. To evaluate pulmonary function, we measured forced vital capacity (FVC) and forced expiratory volume in 1.0 second (FEV1.0). Subjects performed 3 familiarization trials before measurements.

Trunk-muscle strength was measured by Isoforce GT-350 (OG Giken Co, Ltd, Japan), for which high reliability and validity are attested.²² Subjects were asked to sit on a chair in 90° flexion at the hip and knee joints and perform 3 trials of isometric trunk extension and flexion with maximal voluntary effort. The average of 3 trials was used as the measurement value.

The exercise group performed the respiratory-muscle exercises with the Spiro Tiger (Idiag Co, Switzerland; Figure 2), a device consisting of a handheld unit with a respiratory pouch and a base station. The device allows for personalized respiratory exercises through maximal inspirations and expirations without hypocarbia. Individual exercise target values are entered into the base unit and are used to monitor breathing frequency and depth during exercise. The base station in the handheld computer monitors breathing frequency, sets threshold limits for breathing patterns, and displays visual and acoustic feedback to enable the subject to breathe within the threshold values for isocapnia.²³ The base station also stores the time and frequency of each exercise session. This device trains both inspiration and expiration muscles by resistance of a magnetic splint inside a respiratory tube and geared for strength and endurance of the respiratory muscles. The exercise group exercised for 10 minutes thrice a week for 4 weeks. Typically, respiratory-muscle exercises in endurance exercise for athletes are performed for ~15 minutes.^{24,25} However, the intervention time was 10 minutes in this study, because we were investigating not endurance but muscle function. The frequency and the intervention period followed those of a previous study.^{26,27}

Table 1 Subject Characteristics, Mean \pm SD

Group	Gender, M:F	Age, y	Height, cm	Weight, kg
Exercise	8:5	16.1 \pm 0.6	166.3 \pm 8.6	57.8 \pm 9.2
Control	8:5	17.6 \pm 1.8	169.2 \pm 5.9	60.2 \pm 7.6

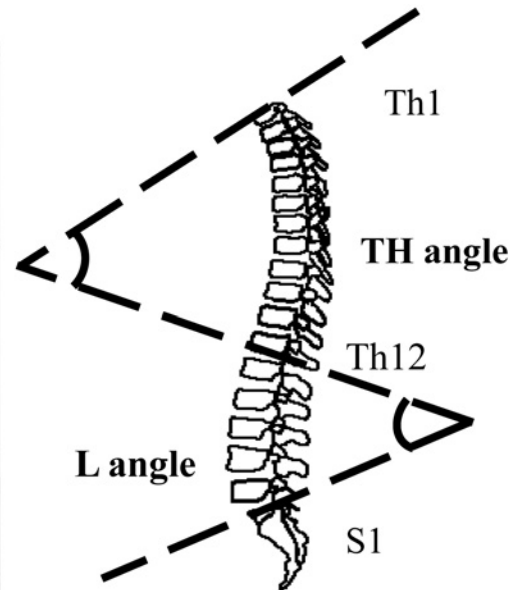


Figure 1 — Measurement of spinal curvature. Th, thoracic; L, lumbar.

Personal training target values are entered into the base unit and used to monitor breathing frequency ($1.5 \times$ the rest time frequency; average 28.1 times/min) and depth (the respiratory pouch the nearest to 50%FVC, 2.0-L pouch, 5 swimmers; 2.3-L pouch, 8 swimmers) during training. The exercise group was instructed to inflate and deflate the respiratory pouch completely and breathe according to the tempo of a sound from the base station. The training target was constant throughout intervention. Participants in both groups continued swim training throughout the intervention. After 4 weeks, spinal curvature and pulmonary function were measured again for both the exercise and control groups. The data were compared preexercise and postexercise between the groups.

This study was approved by the Hiroshima University Department of Physical Therapy and Occupational Therapy Sciences ethical review board. We obtained informed consent from all the subjects and their parents before the study. No research grants contributed to the study.

Statistical Analyses

A Wilcoxon signed rank-sum test was used to compare preexercise and postexercise values, and a Mann-Whitney U test was used to compare the exercise and control groups, with the significance level of $<5\%$. StatView 5.0 (SAS Institute, Cary, NC) was used for data analysis.

Results

The spinal-curvature angles are shown in Table 2. Statistical analysis revealed a significant difference within the exercise group for the preexercise to postexercise values for all parameters measured, indicating a decrease in the TH (-13.1%) and L (-17.7%) angles after the intervention



Figure 2 — Respiratory-muscle exercise.

($P < .05$). There are no differences in initial dates between the groups. However, the exercise group presented with lower TH (-8.6%) and L (-20.9%) angles postexercise than the control group ($P < .05$).

The muscle strengths for trunk flexion and extension are shown in Table 3. These results indicated a significant increase only in trunk-flexion strength from preexercise to postexercise in the exercise group ($+10.6\%$, $P < .05$). There was no significant difference in trunk strength

Table 2 Change in Spinal Curvature, Mean \pm SD

Group	Thoracic Angle, °		Lumbar Angle, °	
	Preexercise	Postexercise	Preexercise	Postexercise
Exercise	41.7 \pm 5.1**	36.2 \pm 5.1**†	17.5 \pm 4.3*	14.4 \pm 4.6*†
Control	39.4 \pm 3.4	39.6 \pm 5.5†	18.5 \pm 4.4	18.2 \pm 4.6†

*Pre vs post, $P < .05$; **pre vs post, $P < .01$; †ex vs cont, $P < .05$.

Table 3 Changes in Trunk-Muscle Strength, Mean \pm SD

Group	Trunk Flexion, N		Trunk Extension, N	
	Preexercise	Postexercise	Preexercise	Postexercise
Exercise	695.4 \pm 175.2*	769.2 \pm 179.7*	628.0 \pm 217.7	628.3 \pm 191.9
Control	687.6 \pm 113.6	681.0 \pm 95.3	715.8 \pm 181.2	714.6 \pm 170.7

*Pre vs post, $P < .05$.

Table 4 Changes in Pulmonary Function, Mean \pm SD

Group	Forced Vital Capacity, L		Forced Expiratory Volume in 1.0 s, L	
	Preexercise	Postexercise	Preexercise	Postexercise
Exercise	4.1 \pm 0.7**	4.3 \pm 0.8**	3.4 \pm 0.6**	3.7 \pm 0.5**
Control	4.2 \pm 0.7	4.2 \pm 0.8	3.9 \pm 0.8	3.9 \pm 0.8

**Pre vs post, $P < .01$; †ex vs cont, $P < .05$.

between the groups with respect to the preexercise and postexercise values.

The pulmonary-function values are shown in Table 4. FVC (+4.5%) and FEV1.0 (+8.8%) were significantly increased after 4 weeks for the exercise group ($P < .01$). There were no differences in the FVC and FEV1.0 values for the 2 groups.

Discussion

Swimmers can be plagued by joint pain and dysfunction, which are attributed to several factors including posture.⁷ For example, thoracic hyperkyphosis encumbers motions of the scapulothoracic joint⁸ and leads to swimmer's shoulder.⁶ Improvement in posture is essential to prevent and treat injury.²⁸ This study examined the effects of a 4-week respiratory-muscle exercise intervention on spinal curvature and trunk-muscle strength. Our results indicated that the exercise significantly decreased the TH and L angles and increased trunk-flexion-muscle strength and pulmonary function. Decreased spinal curvature leads to adaptive changes in the pelvis and lower limbs and improves posture.²⁹ Therefore, we believe that the exercises targeted muscles that contribute to improved posture. Furthermore, we observed

between-groups differences for thoracic kyphosis and lumbar lordosis after the intervention. Increased spine curvature is responsible for low back pain^{4,5} and swimmer's shoulder,⁶ so respiratory-muscle exercise may prevent these dysfunctions.

In this study, FVC and FEV1.0 values were elevated in the exercise group at the end of the intervention. Similar results have been demonstrated by a previous study without FEV1.0.³⁰ This confirms the effect of respiratory-muscle exercise in improving pulmonary function.

The preexercise thoracic and lumbar curvatures in this study are similar to those in another Japanese study,³¹ and the postexercise curves in the exercise group are better than that. These results showed that curvatures improved.

The postexercise thoracic and lumbar curvatures were smaller than the preexercise curvatures. Because muscle strength for trunk flexion was noted to increase only in the exercise group, we conclude that the exercises strongly affected the abdominal muscles. Abe et al³² reported that the transverse abdominal muscle is the most powerful in the abdominal muscle group with respect to respiration. The transverse abdominal muscle may have been specifically targeted in this exercise. This important muscle is a key local stabilizer. Contraction of the transverse abdominis increases intra-abdominal pressure, which leads to lumbar

straightening.³³ In addition, a rise in intra-abdominal pressure presses the rib cage upward and effectively allows the extension of the thoracic vertebrae.³⁴ In addition, we attribute the decrease of thoracic curvatures to a stretching effect on the thorax. In a previous study, Izumizaki et al³⁵ reported that thoracic capacity and rib-cage movement were changed by thixotropy, which is the exercise of maximal expiration from maximum inspiration. The stiffness of the rib cage leads to thoracic kyphosis.³ In this study, repetitive deep breathing resolved the stiffness of the rib cage and straightened thoracic kyphosis. This process may be responsible for altering the spinal curvature.

In contrast, trunk-extension-muscle strength was not altered. In quiet breathing, inspiration requires muscle contractions. However, expiration occurs naturally via the elasticity of the respiratory apparatus. Our subjects respired faster and deeper than in common respiration during the respiratory exercises. The respiratory-muscle exercise may thus affect abdominal muscles that do not normally play a role in breathing at rest, and it may not have any effect on back muscles that typically work in breathing at rest.

Emery et al³⁶ reported that subjects showed smaller static thoracic kyphosis during quiet sitting and greater abdominal strength after 12 weeks of Pilates training, and Scannell and McGill³⁷ noted that the lumbar curvature of their subjects with hyperlordosis became less lordotic, decreasing their standing lumbar lordosis by 10° after 12 weeks of trunk-muscle training. These training methods require a long period of 12 weeks for improvement. By contrast, our intervention period was 4 weeks, so spinal alignment may be improved in a much shorter period. In addition, if respiratory-muscle exercise is combined with stretching used in the previous study, further effects may be expected.

Our study has certain limitations: (1) The reason underlying the altered alignment is a matter of speculation because muscle function was not measured. (2) The effect of changes in curvature on performance or injury treatment or prevention remains unclear. (3) There was no placebo group. (4) There was no measure of respiratory-muscle strength or endurance. (5) The authors were not blinded to the study. Further studies are required to clarify these issues.

Conclusion

Our study examined the effectiveness of respiratory-muscle exercise to both increase trunk-muscle strength and correct spinal curvature in adolescent swimmers. The results suggest that respiratory-muscle exercise straightens the spine, possibly by stimulating the local stabilizers.

References

1. Wojtys EM, Ashton-Miller JA, Huston LJ, Moga PJ. The association between athletic training time and the sagittal curvature of the immature spine. *Am J Sports Med.* 2000;28:490–498.

2. Hellström M, Jacobsson B, Swärd L, Peterson L. Radiologic abnormalities of the thoraco-lumbar spine in athletes. *Acta Radiol.* 1990;31:127–132.
3. Shirley S. *Diagnosis and Treatment of Movement Impairment Syndromes.* St Louis, MO: Mosby Inc; 2002.
4. Glassman SD, Bridwell K, Dimar JR, Horton W, Berven S, Schwab F. The impact of positive sagittal balance in adult spinal deformity. *Spine.* 2005;30:2024–2029.
5. Morel E, Ilharreborde B, Lenoir T, et al. Sagittal balance of the spine and degenerative spondylolisthesis. *Rev Chir Orthop Reparatrice Mot.* 2005;91:615–626.
6. Kennedy JC, Hawkins RJ. Swimmer's shoulder. *Phys Sportsmed.* 1974;2:34–38.
7. Allegrucci M, Whitney SL, Irrgang JJ. Clinical implications of secondary impingement of the shoulder in freestyle swimmers. *J Orthop Sports Phys Ther.* 1994;20:307–318.
8. Ludewig PM, Reynolds JR. The association of scapular kinematics and glenohumeral joint pathologies. *J Orthop Sports Phys Ther.* 2009;39:90–104.
9. Kendall FP, McCreary EK, Kendall HO. *Muscles, Testing and Function.* 4th ed. Baltimore, MD: Williams & Wilkins; 1993.
10. Bergmark A. Stability of the lumbar spine: a study in mechanical engineering. *Acta Orthop Scand.* 1989;230(Suppl):20–24.
11. Cholewicki J, Panjabi M, Khachatryan A. Stabilizing function of trunk flexor-extensor muscles around a neutral spine posture. *Spine.* 1997;22:2207–2212.
12. Gardner-Morse M, Stokes IA, Laible JP. Role of muscles in lumbar spine stability in maximum extension efforts. *J Orthop Res.* 1995;13:802–808.
13. Willardson JM. Core stability training: applications to sports conditioning programs. *J Strength Cond Res.* 2007;21:979–985.
14. Lust KR, Sandrey MA, Bulger SM, Wilder N. The effects of 6-week training programs on throwing accuracy, proprioception, and core endurance in baseball. *J Sport Rehabil.* 2009;18:407–426.
15. McMillan A, Proteau L, Lebe R. The effect of Pilates-based training on dancers' dynamic posture. *J Dance Med Sci.* 1998;2:101–107.
16. Fitt S, Sturman J, McClain-Smith S. Effects of Pilates-based conditioning on strength, alignment, and range of motion in university ballet and modern dance majors. *Kinesiol Med Dance.* 1994;16:36–51.
17. Greendale GA, Huang MH, Karlamangla AS, Seeger L, Crawford S. Yoga decreases kyphosis in senior women and men with adult-onset hyperkyphosis: results of a randomized controlled trial. *J Am Geriatr Soc.* 2009;57:1569–1579.
18. Decramer M. Response of the respiratory muscles to rehabilitation in COPD. *J Appl Physiol.* 2009;107:971–976.
19. Gigliotti F, Binazzi B, Scano G. Does training of respiratory muscles affect exercise performance in healthy subjects? *Respir Med.* 2006;100:1117–1120.
20. Campbell EJM, Agostoni E, Davis JN. *The Respiratory Muscles: Mechanics and Neural Control.* London: Hodder Arnold H&S; 1970.
21. Mannion AF, Knecht K, Balaban G, Dvorak J, Grob D. A new skin-surface device for measuring the curvature and global and segmental ranges of motion of the spine: reliability of measurements and comparison with data reviewed from the literature. *Eur Spine J.* 2004;13:122–136.
22. Kawamura K, Otsuka H, Nishikawa H, Fujii M. Standardized normal strength values for adult trunk muscles. *J Phys Med.* 2002;13:145–150.

23. Sartori R, Barbi E, Poli F, et al. Respiratory training with a specific device in cystic fibrosis: a prospective study. *J Cyst Fibros*. 2008;7:313–319.
24. Romer LM, McConnell AK, Jones DA. Effects of inspiratory muscle training on time-trial performance in trained cyclists. *J Sports Sci*. 2002;20:547–562.
25. Romer LM, McConnell AK, Jones DA. Effects of inspiratory muscle training upon recovery time during high intensity, repetitive sprint activity. *Int J Sports Med*. 2002;23:353–360.
26. Fairbairn MS, Coutts KC, Pardy RL, McKenzie DC. Improved respiratory muscle endurance of highly trained cyclists and the effects on maximal exercise performance. *Int J Sports Med*. 1991;12:66–70.
27. Leddy JJ, Limprasertkul A, Patel S, et al. Isocapnic hyperpnea training improves performance in competitive male runners. *Eur J Appl Physiol*. 2007;99:665–676.
28. Lynch SS, Thigpen CA, Mihalik JP, Prentice WE, Padua D. The effects of an exercise intervention on forward head and rounded shoulder postures in elite swimmers. *Br J Sports Med*. 2010;44:376–381.
29. Roussouly P, Nnadi C. Sagittal plane deformity: an overview of interpretation and management. *Eur Spine J*. 2010; in press.
30. Verges S, Boutellier U, Spengler CM. Effect of respiratory muscle endurance training on respiratory sensations, respiratory control and exercise performance: a 15-year experience. *Respir Physiol Neurobiol*. 2008;161:16–22.
31. Kawasaki H, Ito H, Masegaki A, Ono D, Watarai K. Comparison of spinal sagittal alignment and mobility among standing, sitting, and four point kneeling postures. *Jap J Phys Fitness Sports Med*. 2009;58:517–526.
32. Abe T, Kusuvara N, Yoshimura N, Tomita T, Easton PA. Differential respiratory activity of four abdominal muscles in humans. *J Appl Physiol*. 1996;80:1379–1389.
33. Richardson C, Hodges P, Hides J. *Therapeutic Exercise for Lumbopelvic Stabilization*. 2nd ed. Edinburgh, UK: Churchill Livingstone; 2004.
34. Kapandji IA. *The Physiology of the Joint*, Vol. 3: *The Trunk and Vertebral Column*. London, Churchill Livingstone, 1998.
35. Izumizaki M, Ohshima Y, Iwase M, Homma I. Chest wall motion after thixotropy conditioning of inspiratory muscles in healthy humans. *J Physiol Sci*. 2006;56:433–440.
36. Emery K, De Serres SJ, McMillan A, Côté JN. The effects of a Pilates training program on arm-trunk posture and movement. *Clin Biomech (Bristol, Avon)*. 2010;25:124–130.
37. Scannell JP, McGill SM. Lumbar posture—should it, and can it, be modified? a study of passive tissue stiffness and lumbar position during activities of daily living. *Phys Ther*. 2003;83:907–917.