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Original Article

Effects of different core exercises on respiratory parameters and abdominal strength

Luca Cavaggioni[1)]*, Lucio Ongaro[1)], Emanuela Zannin[2)], F. Marcello Iaia[1)], Giampietro Alberti[1)]

[1)] *Department of Biomedical Sciences for Health, Università degli Studi di Milano: Via G. Colombo 71, 20133 Milan, Italy*
[2)] *TBM Lab, Dipartimento di Bioingegneria, Politecnico di Milano, Italy*

Abstract. [Purpose] This study determined the effects a new modality of core stabilization exercises based on diaphragmatic breathing on pulmonary function, abdominal fitness, and movement efficiency. [Subjects] Thirty-two physically active, healthy males were randomly assigned to an experimental group (n = 16) and a control group (n = 16). [Methods] The experimental group combined diaphragmatic breathing exercises with global stretching postures, and the control group performed common abdominal exercises (e.g., crunch, plank, sit-up), both for 15 minutes twice weekly for 6 weeks. Pulmonary function (measured by forced vital capacity, forced expiratory volume in 1 second, and peak expiratory flow) and abdominal fitness (measured with the American College of Sports Medicine curl-up [cadence] test and the Functional Movement Screen™) were evaluated before and after the intervention. [Results] Significant changes in curl-up (cadence) test scores, Functional Movement Screen scores, and all pulmonary parameters were recorded in the experimental group at the posttraining assessment, whereas in the control group, no significant differences over baseline were observed in any parameters. [Conclusion] Compared with traditional abdominal exercises, core stabilization exercises based on breathing and global stretching postures are more effective in improving pulmonary function and abdominal fitness.
Key words: Respiratory parameters, Core stability, Diaphragmatic breathing

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INTRODUCTION

In recent years, abdominal muscle training has gained increasing popularity, and exercises like "crunches" or "planks" have become an integral part of both fitness and rehabilitation programs. Abdominal training serves to improve core stability, which is the ability to strengthen the lumbopelvic complex and transfer forces from the upper to the lower limbs of the body while maintaining the spine in a neutral position[1, 2)]. The "core" region of the body has been anatomically described as a box, with the abdominals at the front, spinal and gluteal muscles at the back, the diaphragm on the top, and the pelvic floor and hip muscles on the bottom[3)]. Generally, the core muscles, which form the primary muscle group for maintaining spinal stability[4)], can be divided into two groups according to their functions and attributes: local system and global system[5)].

The most common traditional exercises[21)] and training methods to enhance abdominal strength and stability employ body weight exercises consisting of static or dynamic contractions in various body positions (e.g., supine, lateral), starting with isolated movements and then continuing through with more complex sequences[1, 6)] such as crunches, sit-ups, and planks (prone or lateral). However, such exercises, especially the crunch, are performed with repeated flexions and lateral bending motions that produce vertebral compression at high lumbar overloads and therefore may be injurious for the spine[7–11)].

Correct breathing (especially as it involves the respiratory muscles) is vital to abdominal training because respiratory muscles are directly involved during common core stability exercises[12–14)]. DePalo et al. found that the diaphragm is actively recruited in many resistance training exercises, including sit-ups[13)]. Other studies demonstrated that the respiratory muscles are involved in a variety of activities in which respiration is not primarily involved[12, 13, 15, 16)]. Because breathing is one of the most basic patterns directly related to human movement[17)], as seen in neonates[18, 19)], inefficient breathing may result in muscular imbalance and motor control alterations that can affect general motor quality[17)].

To our knowledge, few publications to date have evaluated the impact of breathing in relation to abdominal exercises. Our hypothesis was that exercises based on a combination of global stretching postures, which are advantageous for improving respiratory apparatus efficiency[20)], and breathing exercises may exert a concurrent positive effect on core function and body movement. The aim of this study was

*Corresponding author. Luca Cavaggioni (E-mail: cavaggioni.luca@gmail.com)

to evaluate whether, as compared with a training protocol of common exercises[21], abdominal training plus breathing exercises would more greatly enhance abdominal fitness, quality of movement, and respiratory function.

SUBJECTS AND METHODS

All participants gave their written informed consent after having been informed about the objectives and scope, procedures, risks, and benefits of the study. Participation was voluntary, and withdrawal from the study was permitted at any time. All procedures were carried out in accordance with the Declaration of Helsinki; the study protocol was approved by the university's institutional review board.

The study sample comprised 32 healthy male nonsmokers without pulmonary disease or a history of low back pain (Experimental group [EG] n = 16, mean age 30 ± 2 years, height 1.73 ± 3 m, weight 67 ± 2 kg; control group [CG], n = 16, mean age 28 ± 3 years, height 1.76 ± 2 m, weight 70 ± 3 kg). Before the start of the study, all subjects engaged in regular physical activity at least 3 times per week with a training regimen that included medium-intensity aerobic activity (65–75% heart rate maximum) for at least 45 minutes and a resistance training program that included free-weight and machine exercises to 60–70% of one repetition maximum (1RM) for 2 days per week. The subjects were matched and randomly assigned to two groups as determined by a chance process (a random number generator on a computer) that could not be predicted. Each group performed the assigned exercise protocol for 15 minutes twice weekly. Data were collected before and after 6 weeks of training. No other physical exercise, aside from that specified for the purposes of this study, was performed during the study period.

Respiratory measurements were taken with the subjects comfortably seated and the trunk at a 90° angle. Pulmonary function was measured with a portable spirometer (Pony FX, Cosmed, Rome, Italy) while the subjects were wearing a nose clip. The spirometer volume was calibrated with a 3 L syringe before each test. The test was repeated three to five times to obtain at least two acceptable trials (variability <100 mL), with a 2-minute rest interval between the trials to ensure adequate recovery. The best trial result for each subject was used for analysis. Respiratory measurements were taken according to general guidelines[22].

A single experienced investigator interpreted the data according to established guidelines[23] to obtain a target value for each subject and to ensure that the maneuver had been performed correctly. Forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), and peak expiratory flow (PEF) were evaluated.

The American College of Sports Medicine (ACSM) curl-up (cadence) test and the Functional Movement Screen (FMS)™, two simple, practical, valid, and reliable tests[17, 24–26], were used to assess abdominal muscle fitness. The ACSM curl-up (cadence) test evaluates local muscular endurance of the abdominal muscle groups, which are important for good posture and performing various daily tasks. The FMS™ evaluates the efficiency of basic human motion, for example, as during breathing; a proper breathing pattern in turn influences movement efficiency[17, 24].

The ACSM curl-up (cadence) test protocol is carried out with the subject lying on his or her back on a mat with knees bent at a 90° angle and feet on the floor. The arms are extended to the sides with the fingers touching a piece of masking tape. A second piece of tape is placed 12 cm beyond the first piece. For this study, the metronome was set to 40 beats per minute. At the first beep, the subject lifts his or her shoulder blades off the mat by flexing the spine until the fingertips reach the second piece of tape. At the next beep, the subject slowly returns the shoulder blades to the mat by flattening the lower back. The subject performs as many curl-ups as possible without stopping, up to a maximum of 75 repetitions[24].

The FMS™, developed by Cook & Burton[27–29], consists of seven patterns: deep squat, hurdle step, in-line lunge, shoulder mobility, active straight leg raise, trunk stability push-up, and rotary stability. Movement competency is graded on a scale from 0 to 3 points based on how the tasks are accomplished: 0 indicates movement with pain, 1 indicates inability to perform the pattern, 2 indicates pattern performed with compensations or imperfections, and 3 indicates pattern performed as directed. Instruction and administration of the FMS™ were carried out by a certified FMS™ instructor according to published guidelines[27–29].

The two training protocols were administered for 15 minutes twice per week for 6 weeks in both groups; all exercises were performed after a standardized 10-minute warm-up consisting of cycling on a stationary bike. The EG exercises were focused on achieving and maintaining a proper diaphragmatic breathing pattern for 2–3 seconds during inspiration and 8–10 seconds during expiration, with a vocal sound emitted to induce active recruitment of the pelvic floor muscles and deep internal abdominals[30–32]. To do this, the subject inhales, expanding the lower abdominal region, the side and back of the abdomen, and the lower ribs. The chest is kept relaxed without pushing out the stomach, and the head is aligned with the spine to avoid excessive bending of the spine or body compensations. The exercise sequence is as follows:

1. The subject lies supine with legs extended and arms overhead. On inhalation, he or she stretches the arms upward, and on exhalation, produces a sound from the mouth, maintaining the spine aligned and stretched.
2. The subject sits with the spine erect, lower limbs elongated, and arms extended in front of the chest. During exhalation, a vocal sound is produced while elongating the spine more vertically.
3. The subject sits in a kneeling position with buttocks resting on his heels and legs slightly apart; the face is directed forward with the left arm bent overhead. During exhalation, a sound is produced while starting to bend the body laterally and stretching the opposite side of the body.
4. The subject sits in a kneeling position, with one arm bent in front of the eyes and the other resting on the floor. During inhalation, the trunk is rotated to the right while maintaining normal spinal curvature. During exhalation, a vocal sound is produced while keeping the body rotated and elongated.

The entire routine consists of 2 sets per exercise for 6 repetitions.

Table 1. Results of pulmonary function tests (mean ± SEM) between the experimental and control groups

Parameters	Groups	Values		Gains	
		Before testing	After testing	% change (before and after training)	% change (EG vs. CG)
FVC (L)	EG	5.0 ± 0.2	5.6 ± 0.2	12.2[a]	12.5[b]
	CG	4.9 ± 0.3	5.0 ± 0.2	1.6	
FEV_1 (L)	EG	4.1 ± 0.1	4.6 ± 0.1	11.5[a]	9.2[b]
	CG	4.0 ± 0.3	4.2 ± 0.2	5.2	
PEF (L/second)	EG	8.4 ± 0.4	9.8 ± 0.4	15.6[a]	13.4[b]
	CG	8.3 ± 0.8	8.6 ± 0.6	3.4	

[a]Significant difference between conditions before and after testing ($p<0.05$) in the same group.
[b]Significant difference between groups after exercise training ($p<0.05$).
FVC: forced vital capacity; FEV_1: forced expiratory volume in 1 second; PEF: peak expiratory flow; EG: experimental group; CG: control group

The CG exercises were chosen from a variety of common exercises[21)] during which a spontaneous breathing rhythm (1 second for inspiration and 1 second for expiration) is maintained in the following sequence:

1. Crunch: The subject lies on his back with knees bent, feet on the floor, and hands resting on the chest. During inhalation, the shoulders are lifted off the ground; during exhalation, the subject returns to the starting position.

2. Crunch with rotation: The subject lies on his back with knees bent and feet on the floor. During exhalation, the trunk is lifted and rotated; during inhalation, the subject returns to the starting position.

3. Supine bridge: The subject lies on his back with knees bent and feet on the floor. During exhalation, the pelvis is lifted an inch off the floor while pressing into the soles of the feet. During inhalation, the subject returns the pelvis to the floor.

4. Prone bridge: The subject begins prone in a "table position" with knees under the hips and arms under the shoulder; on inhalation, the right leg is simultaneously lifted straight out and behind, and the left arm is lifted straight out in front.

The routine for exercise numbers 1 and 2 consisted of two series of 15 repetitions each. Exercise numbers 3 and 4 consisted of two series for 10 seconds in isometric contraction. All sessions were supervised by an expert instructor to ensure that the exercises were properly performed.

Data were entered into a personal computer, and all statistical analyses were performed using the Statistical Package for the Social Sciences IBM™ SPSS™ version 21.0 (IBM Corp., Armonk, NY, USA). All data are presented as mean ± SEM ranges. Results were tested for normal distribution using a Shapiro-Wilk test. Two-way [time (before vs. after) 2 group (EG vs. CG)] repeated analysis of variance (ANOVA) tests were used to measure differences in respiratory parameters, ACSM curl-up (cadence) test scores, and FMS scores, followed by Tukey's test. A dependent-measure t-test was used to determine pre- and posttest differences between the groups. Significance was set at $p<0.05$. Partial eta squared (Part η^2) effect size was used to estimate the magnitude of the difference within each group; the thresholds for small, moderate, and large effects were defined as 0.01, 0.06, and 0.14, respectively[33)].

RESULTS

All subjects completed the assigned training routine. There was no significant difference in any of the measurements between the two groups at baseline. Table 1 presents the differences in respiratory measurements before and after exercise training. FVC improved by 12.2% ($p<0.05$) (5.06 ± 0.2 L pretraining vs. 5.68 ± 0.2 L posttraining) in the EG, while it remained unchanged in the CG (4.97 ± 0.3 L pretraining vs. 5.05 ± 0.2 L posttraining). After training, there was a significant increase in FEV_1 (12.5%) with a "moderate" effect size (0.07) in the EG as compared with the CG. A significant difference between pre- and posttraining FEV_1 was observed (11.5%, from 4.14 ± 0.1 L to 4.62 ± 0.1 L) in the EG as compared with the CG (5.2%, 4.02 ± 0.3 L and 4.23 ± 0.2 L). After 6 weeks of training, FEV_1 was 9.2% higher on average ($p<0.05$) in the EG than in the CG. There was a significant increase of 15.6% in PEF (from 8.49 ± 0.4 L/second at baseline to 9.82 ± 0.4 L/second at the end of training) in the EG compared with the CG (3.4%, from 8.37 ± 0.8 L/second pretraining to 8.66 ± 0.6 L/second posttraining). After 6 weeks of training, PEF was 13.4% greater in the EG than in the CG.

Table 2 reports the mean functional test scores of subjects before and after training. The EG improved by 34.3%, from 40 ± 1.01 to 54 ± 1.1 ($p<0.05$) on the ACSM curl-up (cadence) test, whereas the increase in the number of repetitions was lower in the CG (39 ± 2.8 to 43 ± 3.4; $p<0.05$). After 6 weeks of training, there was a significant difference of +25.6% ($p<0.05$) with a "large" effect size (0.12) in the EG as compared with the CG. There was a significant difference in the FMS scores (11 ± 2.6 arbitrary unit au, pretraining vs. 16 ± 2.0 au posttraining; $p<0.05$) in the EG as compared with the CG, in which improvements were smaller (11.0 ± 0.3 au pretraining vs. 11.7 ± 0.4 au posttraining). A significant increase of +41% ($p<0.05$) with a "large" effect size (0.13) was seen in the EG as compared with the CG.

DISCUSSION

The main finding of this study is that, compared with traditional exercises, a program including core exercises performed with a focus on muscular chain stretching and

Table 2. Results of functional tests (mean ± SEM) between the experimental and control groups

Parameters	Groups	Values		Gains	
		Before training	After training	% change (before and after training)	% change (EG vs. CG)
ACSM curl-up (cadence) test (number of repetitions)	EG	40.0 ± 1.0	54.0 ± 1.1	34.3[a]	25.6[b]
	CG	39.0 ± 2.8	43.0 ± 3.4	8.1[a]	
FMS™ (a.u.)	EG	11.4 ± 0.6	16.5 ± 0.5	44.7[a]	41.0[b]
	CG	11.0 ± 0.3	11.7 ± 0.4	6.3	

[a]Significant difference between before and after condition ($p<0.05$) inside the same group.
[b]Significant difference between groups post-training ($p<0.05$).
ACSM: American College of Sports Medicine; EG: experimental group; CG: control group; FMS™: Functional Movement Screen™

breathing techniques can lead to greater improvement in respiratory function, abdominal muscle endurance, and movement efficiency. Furthermore, the results suggest that a series of core exercises performed with a vocal sound emission can be a valid strategy to enhance proper diaphragmatic breathing patterns and deep internal abdominal activation[30, 31] much more than in traditional abdominal routines in which people tend to hold their breath or use chest wall respiration[34].

In agreement with published data, our results show that, while traditional core exercises can improve pulmonary function, improvements are greater with muscular chain stretching in combination with breathing techniques. This difference was expected because the exercises were specifically designed to train the respiratory muscles and the diaphragmatic breathing pattern in particular. Indeed, greater improvement in lung function parameters but also in fitness test scores was observed in the EG.

In both groups, the baseline ACSM curl-up (cadence) test and FMS scores were in line with normative data, whereas after training, the scores on both tests were in the above-normal average only in the EG[24, 35]. Specifically, the raw scores of the FMS test, whole body stability and balance patterns, as evaluated for the parameters Rotary Stability and Trunk Stability Push Up, improved from 1.3 au to 2 au in the EG, indicating improved body control due to a better respiratory pattern. In *Shoulder Mobility,* the EG improved from a medium to the highest score (2.4 au before, 3 au after training), whereas the CG remained unchanged with a medium score (2.5 au before, and 2.6 au after training). The same trend was noted on the Active Straight Leg Raise test. Concerning whole body patterns (Deep Squat, Hurdle Step, In Line Lunge), the EG improved from a low to a medium score on each of the three patterns (1.6–2.5 au, 1.4 −2 au, and 1.6–2.4 au, respectively), whereas most values remained unchanged in the CG.

As reported in previous studies, proper diaphragmatic breathing is directly linked to better functional movement[17], but combining proper breathing with global stretching postures can produce a greater effect on such functional parameters, as measured on mobility, stability, and whole body pattern tests. Regarding the biomechanical aspects of breathing, the expiration phase promotes active recruitment of the abdominal muscles, contrasting the natural elevation of the rib cage (induced by raising the arms overhead); to the contrary, elevating the arms raises the anterior chest wall, makes the thoracolumbar column hyperlordotic, and puts the diaphragm in an oblique position that inhibits its proper function. During exhalation, the thoracolumbar spine returns to a more neutral position (opposing the previous hyperlordosis), and the diaphragm is more horizontal without posterior pelvic tilt[34]. The subject should inhale to expand the lower portion of the abdominal region, the side and back parts of the abdomen and lower ribs, keeping the spine aligned and the chest relaxed. Using a correct diaphragmatic breathing pattern promotes co-contraction of the abdominal muscles in the so-called bracing technique, which provides trunk stiffness and stability[36, 37].

When focusing on diaphragmatic breathing, it is important not only to reestablish a correct respiratory pattern but also to ensure lumbar spine stabilization by increasing intra-abdominal pressure[38–41] and activation of the core structures to transfer forces from the center of the body to the lower extremities. To produce an economic breathing pattern, all joints must be centered in a stable position to involve all muscular chains. The head, eyes, and spinal curves should all be aligned with the pelvis and the hips down to the knees and feet. This can be achieved with proper diaphragmatic breathing and adequate muscle tone distribution (as can be trained with EG exercises)[18, 19].

The combined EG exercises may offer several other advantages: first, recruitment of the deep abdominals increases intra-abdominal pressure and coactivation of the entire abdominal wall[34], which has a fundamental role in providing adequate support for spine and trunk stiffness[42, 43]. Second, in contrast with crunches, there are no repeated flexions that could be injurious to the vertebrae[7–9]. Third, the spine remains in a neutral posture[34], so the abdominals can be trained in an elongated and normal position. In sports or activities of daily living, people rarely flex the rib cage to the pelvis, thus shortening the rectus abdominis[9].

The present study has several limitations. The sample size was small, and the subjects did not belong to a specific population. In addition, electromyographic assessment of the abdominal muscles was not performed.

In conclusion, EG exercises that incorporate correct breathing patterns and body flexibility offer an alternative to traditional abdominal exercises. As such, they may be useful for coaches or physical therapists when selecting core exercises to improve overall abdominal fitness and pulmonary function and to retrain correct diaphragmatic breathing and whole body movements. Further research is needed to compare abdominal breathing with other core exercises in order to clarify the combination of breath and abdominal exercises in treating painful disorders (low back pain, neck pain) and improving motor control in fitness and rehabilitation programs.

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