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RESEARCH ARTICLE

THE EFFECTS OF RESPIRATORY MUSCLE FUNCTIONS ON TRUNK MUSCLE ENDURANCE IN HEALTHY YOUNG ADULTS

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ABSTRACT

Purpose: Respiratory muscles play a dual role in breathing and trunk stability during activities. The relationship between respiratory muscle functions and trunk stability has not yet been clarified. The aim of the study was to examine the effects of respiratory muscle functions on trunk muscle endurance in healthy young adults.
Material and Methods: McGill's trunk muscle endurance tests, which consist of trunk flexion endurance test (FE), Sorensen test (ST) and Side Bridge test (SB), were used to evaluate the participants' trunk muscle endurance. Maximal inspiratory and expiratory pressures were measured to determine respiratory muscle strength. The respiratory muscle endurance test was performed with the incremental threshold load protocol using a threshold IMT device.
Results: A total of 51 healthy young adults, with a mean age of 21.8 ± 3.2 years, were evaluated. The results of the linear regression models were significantly explained 46% of the variance in the SB and 38% in the FE, (for SB Adj $R2=0.46$, $F=21.40$, $p<0.001$ and for FE Adj $R2=0.38$, $F=15.65$, $p<0.001$). Respiratory muscle endurance contributed 30% to the endurance of the trunk flexor muscles, while respiratory muscle strength contributed only 8%. Similarly, respiratory muscle endurance contributed 38% to the endurance of the trunk lateral flexor muscles, while respiratory muscle strength contributed only 8%.
Conclusion: Although respiratory muscle strength and respiratory muscle endurance were independent contributors to trunk muscle endurance, respiratory muscle endurance more affected trunk muscle endurance than respiratory muscle strength in healthy young adults.

Keywords: Endurance, respiratory muscles, strength, trunk muscles

INTRODUCTION

In the last decades, the number of studies investigating the importance of muscle endurance has increased. The terms of muscle strength and muscle endurance refer to different functions of the muscles. Muscle strength is the ability of a muscle or muscle group to withstand a resistance (1), however, the muscle endurance is defined as maintaining the muscle or muscle group's ability to sustain of withstanding applied resistance (2). In addition, the measurements of endurance are task-specific for each muscle. Muscle strength, one of the main components of health and physical fitness, has an important role in the performance of many activities in daily life, while muscle endurance is related to the resistance of a muscle or muscle group to fatigue.

Respiration that is autonomous and rhythmic is one of the basic functions ensuring the continuity of life. It must be sustainable under all conditions, and therefore many muscles have to work in harmony (3). Respiratory muscles are classified according to the respiratory phase in which they are active. In the inspiratory phase of respiration, the diaphragm, external intercostal and scalene muscles are active. In the expiratory phase, the transversus abdominis (TrA) muscle, the internal oblique (IO) muscle, the external oblique (EO) muscle, the rectus abdominis (RA) muscle, and the internal intercostal muscles between the ribs are active. Respiratory muscle performance can be evaluated in terms of strength and endurance. Although respiratory muscle strength and endurance appear to be closely linked in many cases, endurance can't be accurately predicted from strength measurements (2). It has been shown that respiratory muscle strength is decreased while respiratory muscle endurance increases in patients with cystic fibrosis (4). Respiratory muscle strength has a positive effect on lung volumes and provides greater ventilation of the lungs. However, the endurance of the respiratory muscles is related to the fatigue of the respiratory muscles and allows the respiratory muscles to maintain their ability to do work (4, 5). Respiratory muscle strength and respiratory muscle endurance are parameters that can be improved with respiratory muscle training. Although respiratory muscle training increases respiratory muscle strength, the increase in respiratory muscle endurance better reflects clinical improvement than respiratory muscle strength (6, 7).

Respiratory muscles in humans play a dual role in breathing and trunk stability during activities. It has been shown that the diaphragm, the main inspiratory muscle, is also active during trunk activities. Although the diaphragm does not reveal direct action on the spine, it plays an important role in providing and maintaining core stability by increasing abdominal pressure. Besides, the diaphragm is stimulated before the muscles that initiate the limb movements, thereby playing a substantial role in core stability during limb movements (8). Even that the number of studies examining the effect of respiratory muscle training on trunk stability has increased recently (9-11), the relationship between respiratory muscle functions and the trunk stability has not yet clear. The aim of this study is to examine the effects of respiratory muscle functions on trunk muscle endurance in healthy young adults.

MATERIAL AND METHODS

Study Design and Participants

After the ethics committee's approval, a total of 51 healthy young participants with an age range of 18 to 25 years were included in this cross-sectional study. Since the lungs of healthy individuals between the ages of 18 to 25 years complete their physiological maturation and the lung tissue starts to deteriorate with age after this age range, our study includes only individuals in this age range (12). The inclusion criteria: not having any spine deformity such as scoliosis, not diagnosed with any orthopaedic, neurological, or cardiorespiratory diseases. Subjects were excluded if they have any previous spinal or abdominal surgeries, a previous or current pregnancy. Subjects were also excluded if they have regular exercise habit or smoking. Regular exercise habit; was defined as subjects that exercising for at least 45 minutes, 3 days a week for the last 6 months. In addition, participants were demanded not to consume caffeine, or eat any food in the 2 hours previous to the study. The respiratory functions, respiratory muscle strength and endurance, were measured for each participant at the same time of day.

Respiratory Muscle Strength

Respiratory muscle strength was evaluated by measuring intraoral maximal inspiratory pressure (MIP) and expiratory pressure (MEP) using an intraoral pressure meter device (Cosmed® Pony FX, Italy) according to the ATS/ERS testing protocol (13). MIP and MEP were measured from residual volume and total lung capacity; the tests were performed in the sitting position, wearing nose clips and using a standard mouthpiece during the maneuver. Measurements were repeated at least five times with one-breath intervals between each other, the highest value among the best three measurements without a difference of 10 cmH_2O or 10% were recorded (14).

Respiratory Muscle Endurance

The respiratory muscle endurance test was performed using a Threshold IMT (Philips® Respironics, Inc) device with the incremental threshold load protocol, which is repeatable, has less learning effect and clear results, according to ATS / ERS (13). During the test period, the participants were asked to maintain an upright position of the trunk. External load was provided by starting with 30-40% of the previously determined MIP value and increasing the MIP value by 5-10% every 2 minutes. The participant was asked to try to complete the test within 10 minutes by breathing through the mouth throughout the test. The last MIP value that the participant could tolerate for 2 minutes was accepted as the respiratory muscle endurance value (13, 15). Before starting the test, it was explained to the participants that if they felt too much dyspnea, palpitations and/or dizziness during the test, they could remove the device and the test would end (16). Measurements were made by a single physiotherapist using a standard chair.

Trunk Muscle Endurance Tests

McGill's trunk muscle endurance tests, which consist of trunk flexion endurance test, Sorensen test and side bridge test, were used to evaluate the participants' trunk muscle endurance (17). A trial test took a few seconds to show participants the position visually and learn the correct position. Participants were asked to take the test position after a 30-second rest, and the command to "start" was given after checking the correctness of the test position. Each test was repeated twice, with a maximum of two stimuli to ensure the correct test positions with 5 minutes of rest between tests. The maximum time in seconds that participants could stay in a static position during the test was recorded using a standard chronometer. The longest duration of the 2 tests that limited at 240 seconds was recorded. All trunk muscle endurance tests were measured by a single physiotherapist.

Trunk flexion endurance test (FE); the participants were positioned on a mat, with 90 degrees of hip and knee flexion in addition to 60 degrees of trunk flexion and also arms crossed over the trunk. The physiotherapist conducting the assessment supported the participant's feet and fixed his feet on the ground (18). The test was terminated when the participant could not maintain the position and time is recorded (17).

Sorensen test (ST); the participants were positioned in the prone position on an examination bed high above the ground. They were asked to keep their bodies outside of the bed with their pelvis, hips and knees on the bed until spina iliaca anterior superiors being at the edge of the bed. The participants were immobilized using a belt at the gluteal line level and supported by the physiotherapist at the ankles. In this position, the time that the arms crossed in front of the trunk and the trunk maintained its horizontal position was recorded. A chair was placed in front of the bed for safety and support when starting the test (17).

Side bridge test (SB); the participants were positioned on the dominant side on a mat in the lateral position with 90 degrees of shoulder abduction and 90 degrees of elbow flexion. The lower extremities were in extension and the upper foot was in front of the lower foot, while the humeral head, trochanter major and lateral malleolus were aligned. In this position, the participants were asked to lift their bodies on their forearms and sides of the feet. The test was terminated when the participants were unable to maintain a straight body position, or the hip fell down (17).

Statistical Analysis

All data were analyzed using SPSS 24.0 for Windows. Normally distributed data were presented as means and standard deviation. A partial correlation analysis was performed to investigate the relationship between the trunk muscle endurance tests and other variables. The multiple regression models were used to examine the effect of respiratory muscle strength and endurance to the contribution of trunk muscle endurance. Multicollinearity issues were verified using an interaction test. If the variation inflation factor (VIF) value was higher than five, it was considered as multicollinearity. The alpha level was set at .05 for all statistical analyses (19).

An a priori power analysis was conducted to determine the necessary number of participants G*Power (version 3.1; Universität Düsseldorf, Düsseldorf, Germany).(20) The required sample size was calculated using a power of 0.80, an effect size of 0.38 (determined from a pilot study based on the correlations between trunk muscle endurance and respiratory muscle endurance), and a 2-tailed design with an alpha value of 0.05. A total of 49 subjects were needed.

Ethical Consideration

Ethical approval was obtained from the Dokuz Eylül University, Non-Invasive Research Ethics Committee (with decision no: 2020/04-37, date: 17/02/2020). The

Table 1. Characteristics of Participants

Parameters	**Participants (n=51)**
Age, years	21.8 ± 3.2
Height, m	1.70 ± 0.09
Weight, kg	64.2 ± 14.6
BMI, kg/m^2	22.0 ± 3.9
Male / Female, n (%)	24 (47.1) / 27 (52.9)
MIP, cmH_2O	61.3 ± 24.1
MEP, cmH_2O	72.8 ± 23.1
RME, cmH_2O	28.8 ± 7.9
Trunk muscle endurance tests	
Trunk flexion endurance test, sec	44.9 ± 13.4
Sorensen test, sec	107.7 ± 38.5
Side Bridge test, sec	46.6 ± 10.9

Data are presented as mean (SD) or n (%). **BMI:** Body mass index; **MIP:** Maximal inspiratory pressure; **MEP:** Maximal expiratory pressure; **RME:** Respiratory muscle endurance; **sec:** seconds.

study was performed in accordance with the ethical standards as laid down in the 1965 Declaration of Helsinki and its later amendments. Informed consent was obtained from all individual participants included in the study.

An abstract of this study was presented at the International Congress of the European Respiratory Society, organized as a Virtual Congress, held on 5-8 September 2021, and published as a congress abstract in a supplement of the European Respiratory Journal.

RESULTS

The mean age and body mass index (BMI) of the participants were 21.8 ± 3.2 years, 22.0 ± 3.9 kg/m2 respectively. The characteristics of participants are presented in Table 1 and the study flow is presented in Figure 1.

The results of the multiple linear regression analysis for SB and FE are presented in Table 2. The best models with dependent variables SB and FE were significant (for both models, $P < 0.001$). The respiratory muscle endurance affected the R2 change in the model that SB was dependent variable by 38% ($\Delta R2 = 0.38$), while respiratory muscle strength affected 8% ($\Delta R2 = 0.08$). Besides, the respiratory muscle endurance affected the R2 change in the model that FE was dependent variable by 30% ($\Delta R2 = 0.30$), while respiratory muscle strength affected 8% ($\Delta R2 = 0.08$) (Table 2).

DISCUSSION

Previous studies have investigated the relationship between respiratory and trunk activations (9-11, 21-26). Although these studies revealed a relationship between respiratory muscle strength and trunk muscle endurance, there appear to be no studies that identify the relationship between trunk muscle endurance and respiratory muscle endurance. Therefore, this study was conducted to investigate the effects of respiratory muscle functions on trunk muscle endurance in healthy young adults. We showed that trunk muscle endurance is associated with both respiratory muscle strength and respiratory muscle endurance. Moreover, respiratory muscle endurance more affected trunk muscle endurance than respiratory muscle strength.

Abdominal pressure increases to reduce the external load on the spine during trunk or extremity movements. If the diaphragm is in a relaxed position while the abdominal pressure increases, the pressure is transferred to the thoracic cavity, and this may cause adverse effects on hemodynamics and also the central nervous system. To prevent these complications, the diaphragm is active during trunk and limb movements so that the transmission of abdominal pressure to the thorax is minimized (23). Trunk muscles contract before limb movements begin and provide postural stability during limb movements. The diaphragm, which is the roof of the structure defined as the core region, contributes to trunk stability by increasing and maintaining abdominal pressure during its contraction (26). More importantly, to maintain postural stability, the diaphragm contracts simultaneously with the transversus abdominis, one of the most important trunk muscles, independently of respiration (27). It has been reported in many studies that respiratory muscles are also active during non-respiratory activities, and it has even been revealed that they can be trained with non-respiratory activities (22-25). In the literature, the relationships between respiratory and trunk muscle functions are mostly based on results from interventional studies. Strongoli et al. (25) measured transdiaphragmatic pressure (Pdi), which provides an estimate of diaphragm activity, during different thirteen core exercises using balloon catheters. They have found that core exercises cause a variety of Pdi and some of which sufficient to produce an inspiratory muscle training stimulus (25). In a study by Depalo et al. (23) to strengthen the diaphragm with non-respiratory exercise, they showed that the diaphragm can be activated and even trained by non-respiratory activities. Mustafaoğlu et al. (22) investigated the effects of core stabilization exercises on respiratory muscle strength. They have demonstrated that patients with substance use disorder, who participated in a 6-week core exercise training program combined with deep breathing, showed statistically significant improvements in MIP and MEP parameters compared with controls. In another study in which stroke patients were randomly divided into two groups, neurodevelopmental core exercises were applied to the one group and dynamic neuromuscular core exercises to the other group for four weeks. Significant increases in respiratory muscle strength were found in both groups after the four-week

Table 2: The Multiple Linear Regression Analysis for Side Bridge and Trunk Flexion Endurance Tests

	B	SE	β	t	p-values	VIF	ΔR^2
Dependent variable: SB[a], sec							
Constant	17.59	4.59		3.825	< 0.001		
RME, cmH_2O	0.71	0.16	0.51	4.553	< 0.001	1.15	0.38
MIP, cmH_2O	0.14	0.05	0.31	2.750	0.01	1.15	0.08
Dependent variable: FE[b], sec							
Constant	12.24	6.03		2.031	0.04		
RME, cmH_2O	0.75	0.21	0.44	3.685	0.001	1.15	0.30
MIP, cmH_2O	0.17	0.07	0.31	2.607	0.01	1.15	0.08

[a] Dependent variable: SB, Model: *Adj* R^2 = 0.46, F = 21.40, $p < 0.001$
[b] Dependent variable: FE, Model: *Adj* R^2 = 0.38, F = 15.65, $p < 0.001$
$p < 0.05$ was considered significant. **SB:** Side bridge; **RME:** Respiratory muscle endurance; **MIP:** Maximal inspiratory pressure; **MEP:** Maximal expiratory pressure; **FE:** Trunk flexion endurance; **B:** Unstandardized beta; **SE:** Standard error; **β:** Beta; t: Student's t test statistic; **VIF:** Variance inflation factor; **ΔR^2:** Change of coefficient of determination; ***Adj:*** Adjusted; **sec:** seconds.

exercise program (24). In the relevant study, the researchers thought this was due to the involvement of the transversus abdominis, internal oblique, external oblique, and diaphragm as common muscles in respiratory and trunk stabilization. Therefore, the relationship between trunk muscles and respiratory muscles provides postural stability. In this study, we found a significant relationship between trunk muscle endurance and inspiratory muscle strength in healthy young adults. This effect has been demonstrated previously by diaphragm contractions during trunk activity, even supported by the improvement in diaphragm strength with core training programs (24-26). Not only trunk stabilization affects respiratory muscle strength, but also respiratory muscle strength also affects trunk stabilization, in other words, there is a mutual effect. Besides, there are studies examining the effect of respiratory muscle training on trunk stability (9-11). The more important task of the diaphragm, which is the most important muscle of respiration, than supporting the core stability is the inspiration phase of breathing (28). This dual task of the diaphragm has made the effect of respiratory muscle training on trunk muscles a topic of interest in the literature. Janssens et al. (9) investigated the effects of high-density inspiratory muscle training (IMT) versus low-density IMT on proprioceptive use during postural control in 28 individuals with low back pain (LBP). After 8 weeks of training, individuals trained high IMT have shown higher back proprioceptive signals during postural control and improvement in inspiratory muscle strength. In another study, Lee et al. (10) have investigated the effect of respiratory muscle training on trunk stability in 33 stroke patients. They applied expiratory muscle training (EMT), IMT and trunk stabilization exercises to one group and only trunk stabilization exercises to the other group. Although there was an increase in transversus abdominis thickness in both groups, this gain was significantly higher in the group, which applied EMT, IMT, and trunk stabilization exercises, than the other. Finta et al. (11) have demonstrated a significant increase in trunk stability in the group in which breathing exercises were combined with trunk exercises in patients with nonspecific low back pain.

To our knowledge, the relationship between respiratory muscle endurance and trunk muscle endurance has not been studied before. Moreover, this study is the first to examine the relationship between respiratory muscle endurance and trunk muscle endurance in this way. However, Shah et al. (29) have compared the maximal voluntary ventilation (MVV) values, which is a respiratory parameter associated with respiratory endurance, in individuals with and without chronic low back pain. They have found that MVV values were lower in individuals with low back pain than those without. They thought that this may be due to the synergistic activation of the diaphragm with the transversus abdominis muscle and the impairment of transversus abdominis activity in individuals with low back pain. In another study, Hackett (30) investigated at if there were any differences in lung function and respiratory muscle strength between individuals who exercised for strength versus endurance. When compared to the strength-trained group, the endurance-trained group generally performed better in terms of lung function and respiratory endurance. Hackett also showed the change in respiratory endurance with the change in MVV values like Shah et al. (29, 30). Yüksel et al. (31) examined the relationship between pulmonary function, respiratory muscle strength, and trunk muscle endurance. They found that pulmonary function and respiratory muscle strength are associated with the endurance of the trunk muscles. In previous studies (9, 21-23, 25, 30, 31), the relationship between trunk muscles and respiratory muscles was examined through trunk muscle activities and only respiratory muscle strength. For this reason, it was either examined how the respiratory muscle strength changed by giving trunk exercises, or core stabilization was evaluated by giving exercises to increase respiratory muscle strength. However, the strength and endurance are different functions for skeletal muscles and most importantly, respiratory muscles are also skeletal muscles (2, 3). The number of mitochondria is the determinant of endurance and studies have shown that muscle strength training and muscle endurance training are based on different mechanisms and their effects on mitochondrial activity are different (32, 33). These findings suggest that endurance may not be improved with strength training alone. In our study, trunk muscle endurance was related to both respiratory muscle strength and endurance. However, we found that respiratory muscle endurance was more contribute to trunk muscle endurance. Respiratory muscle endurance contributed 30% to the endurance of the trunk flexor muscles, while respiratory muscle strength contributed only 8%. Similarly, respiratory muscle endurance contributed 38% to the endurance of the trunk lateral flexor muscles, while respiratory muscle strength contributed only 8%.

This study has some potential limitations. Firstly, dynamic trunk endurance may be more functional than static trunk endurance in healthy young adults. In this study, we only used static endurance tests to evaluate trunk muscle endurance. Secondly, although the relationship between trunk muscle endurance and respiratory muscle endurance was investigated in this study, the lack of measurements of trunk muscle strength limits the evaluation of the relationship with trunk muscle strength. Finally, since this study conducted on a certain age group, our results may not reflect all healthy population.

CONCLUSION

The results of this study show that although respiratory muscle strength and respiratory muscle endurance were independent contributors to trunk muscle endurance, respiratory muscle endurance more affected trunk muscle endurance than respiratory muscle strength in healthy young adults. In addition, we believe that this study will shed light on further studies on the trunk and respiratory muscles. Future studies are needed to investigate the relationship between respiratory muscles activities and trunk muscles activities.

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