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Article

# Does Athletes' Respiratory Muscle Strength Affect Max VO<sub>2</sub> Kinetics?

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**Abstract:** The objective of this study was to investigate the impact of athletes' respiratory muscle strength, as assessed through maximal inspiratory (MIP) and expiratory pressure (MEP), on aerobic endurance, as indicated by maximal oxygen consumption (Max VO<sub>2</sub>) kinetics. Respiratory muscle strength was assessed using a digital spirometer (Pony FX Cosmed, Italy), while maximal oxygen utilization capacity was measured using a breath-by-breath automatic portable gas analysis system (Cosmed K5, Italy). Statistical analysis was conducted utilizing SPSS 22.0. Based on the standardized regression coefficients ( $\beta$ ), it was found that MEP (mean  $\pm$  SD: 130.95  $\pm$  42.82) and inspiratory diaphragmatic circumference values significantly influenced ventilatory equivalent (VE), oxygen consumption (VO<sub>2</sub>), and carbon dioxide production (VCO<sub>2</sub>). Conversely, the remaining predictor variables did not exhibit a significant effect on VE (mean  $\pm$  SD: 134.80  $\pm$  36.69), VO<sub>2</sub> (mean  $\pm$  SD: 3877.52  $\pm$  868.47 ml), and VCO<sub>2</sub> (mean  $\pm$  SD: 4301.27  $\pm$  1001.07 ml). In contrast, measurements of chest circumference (mean  $\pm$  SD: 91.40  $\pm$  10.72 cm), MEP, and diaphragmatic circumference during inspiration (mean  $\pm$  SD: 95.20  $\pm$  10.21 cm) were found to significantly impact Max VO<sub>2</sub> (mean  $\pm$  SD: 58.52  $\pm$  10.74 ml/kg/min), while the other predictor variables did not demonstrate a significant effect on Max VO<sub>2</sub>. Conclusively, the study revealed that measured values of diaphragmatic circumference during inspiration and MEP exerted a notable influence on Max VO<sub>2</sub>, VE, VO<sub>2</sub>, and VCO<sub>2</sub>. Our findings underscore the importance of considering respiratory muscle strength in assessing and enhancing athletes' aerobic performance. These insights contribute to a deeper understanding of the interplay between respiratory function and exercise capacity, offering potential avenues for optimizing training regimens and performance outcomes in athletic contexts.

**Keywords:** respiratory; maximal inspiratory pressure; expiratory pressure; MaxVO<sub>2</sub>; athletes

## 1. Introduction

The respiratory capacity required to ensure adequate oxygen supply to the working muscles and removal of carbon dioxide is determined by the efficiency of gas exchange during external and internal respiration (1,2). Evaluation of functional response by gas analysis obtained during cardiopulmonary exercise test (CPET) is used as a gold standard to identify functional and pathophysiological limitations (1) for scuba divers, pilots, soldiers and professional athletes working under high levels of physical stress. During physical activity, lung ventilation increases with the oxygen requirement of the skeletal muscles and activates the accessory respiratory muscles next to the diaphragm (3). Respiratory muscle function is determined by the strength and endurance of the

respiratory muscles (4). Many studies have shown that inspiratory muscles are fatigued after short periods of high-intensity exercise (5,6), and after long periods of moderate-intensity exercise (7). This fatigue may be a limiting factor that reduces exercise endurance (8,9). It has been determined that fatigue occurs in the diaphragm muscle with increased respiratory need during high intensity exercises of 85% of  $\text{VO}_2\text{max}$  and above. Also, during these exercises, the respiratory muscles share the amount of oxygen consumed (10).

The results of previous studies show that active skeletal muscles and respiratory muscles share the cardiac output and the oxygen consumed during exercise. In order to increase the performance of the working skeletal muscles, it is important to provide respiration economically so that blood can be sent to the relevant parts at a higher rate. However, if the endurance of the respiratory muscles is not sufficient, it is predicted that exercise performance may decrease due to early fatigue of the diaphragm (11). High-intensity exercise causes peripheral vasoconstriction (12). In addition, it triggers the respiratory muscle metaboreflex, a high sympathetic nerve activity that limits blood flow to the working muscles and thus the energy output and consumption required for breathing (12,13).

The strenuous work of the inspiratory muscles is associated with significant neural and cardiovascular consequences. In healthy people, stimulation of inspiratory muscle fatigue by voluntary resistive inspiration has been seen to cause time-dependent increases in muscle sympathetic nerve activity, heart rate (HR) and mean arterial pressure (MAP), and a gradual decrease in arterial blood flow in inactive extremities (14). There is also evidence that the inspiratory muscle metaboreflex is activated by whole-body exercise. It has been seen that leg blood flow is inversely related to respiratory work during high-intensity exercise, and as a result, changes in leg vascular resistance are directly related to the extent of noradrenaline (norepinephrine) release (15). During prolonged intense whole-body exercise in healthy people, the metaboreflex response associated with inspiratory muscle fatigue may limit exercise performance (16). However, if the inspiratory muscle is exercised, triggering of the respiratory muscle metaboreflex can be delayed and performance can be increased (12). Based on the assumption that the role of respiratory muscle strength in athlete performance may be important for maximum effort; the aim of this study was to examine the effect of athletes' respiratory muscle strength measured by maximal inspiratory and expiratory pressure on aerobic endurance (Max  $\text{VO}_2$ ) kinetics.

## 2. Materials and Methods

### 2.1. Study Design and Participant Selection

The participants included in the research consisted of 14 biathlon, 14 judo and 13 cross country athletes (22 men and 19 women), who applied to the Ministry of Youth and Sports, Department of Athlete Health, Performance and Service Quality Standards to become a volunteer participant. Inclusion criteria were being a non-smoker and not having a respiratory tract disease such as asthma, pulmonary tuberculosis, emphysema or chronic bronchitis. Athletes on medication, especially those on cardiac glycoside or  $\beta$ -receptor antagonist-derived drugs, were not included in the study. Athletes who met the inclusion criteria were evaluated on the same day.

After obtaining the demographic information of the athletes (age, year of sport, smoking habits, medication), RFT (respiratory function tests) tests were performed to evaluate respiration and respiratory muscle strength. The circumference measurements of the athletes were recorded by measuring the axilla and subcostal circumferences. Then, the athletes' Max  $\text{VO}_2$  values were measured on the treadmill with a Cpet K5 device, and the data were recorded. The study was approved by Gazi University Ethics Committee (No: 2022-941). The study was conducted in accordance with the Declaration of Helsinki. All participants signed an informed consent form.

**Table 1.** Demographic information of the research group.

Characteristics	Judo		Biathlon		Cross Country	
	Female (N=7)	Male (N=7)	Female (N=6)	Male (N=8)	Female (N=6)	Male (N=7)
Sports Year (Year)	13.14±3.24	12.71±4.07	6.83±2.04	7.13±1.64	6.17±1.72	8.71±2.81
Age (Years)	22.63±3.06	22.62±4.80	19.24±1.46	18.73±2.21	17.83±1.34	20.21±2.81
Height (Cm)	163±7.57	175.93±6.99	161.33±5.06	170.63±4.72	161.42±6.00	174.57±8.40
Body Weight (Kg)	68.59±26.07	91.64±19.11	56.97±5.46	64.81±8.41	51.33±5.82	68.30±9.32

## 2.2. Data Collection Tools

### 2.2.1. Measurement of Chest Circumference

To assess the chest circumference accurately, two distinct methods were employed:

*Axillary Circumference Measurement:* This technique entailed the assessment of chest circumference at two pivotal junctures - during maximal expiration and maximal inspiration. The circumference was gauged from the level of the chest apex, encircling the axilla (or armpit), employing a rigid tape measure to ensure precision (17).

*Subcostal Circumference Measurement:* This approach aimed to capture variations in diaphragmatic circumference. Measurements were conducted during specific respiratory phases - mid-inspiration, maximal expiration, and maximal inspiration. The circumference was evaluated just below the ribcage, utilizing the same rigid tape measure for consistency across assessments (18)

### 2.2.2. Assessment of Respiratory Muscle Strength

Athletes were briefed on the procedures prior to the tests. Respiratory function and respiratory muscle strength were assessed utilizing a digital spirometer (Pony FX Cosmed, Italy). The evaluations were conducted with athletes seated comfortably in an upright position. Throughout the tests, participants utilized a mouthpiece and wore a nose clip. They were instructed to seal their lips tightly around the mouthpiece to prevent any air leakage from the spirometer. To familiarize athletes with the device's operation, a few trial tests were conducted before the formal assessments. Each test was repeated thrice with a maximum rest period of three minutes between trials. The highest measurement score obtained was utilized for statistical analysis. During the maximal voluntary ventilation (MVV) test, athletes were directed to breathe deeply, rapidly, and forcefully for a duration of 12 seconds. Following the completion of the test, athletes were asked to briefly hold their breath to prevent respiratory alkalosis, and the MVV value was recorded. To evaluate respiratory muscle strength, maximum inspiratory pressure (MIP) and maximum expiratory pressure (MEP) tests were administered. For the MIP test, athletes were instructed to fully exhale before taking a deep, rapid, and forceful inhalation. Conversely, for the MEP test, athletes were prompted to inhale fully before exhaling swiftly and forcefully. Each test was repeated thrice with rest intervals between measurement cycles. The most favorable results obtained from all tests were selected for inclusion in the subsequent analysis.

### 2.2.3. Assessment of Aerobic Capacity (MaxVO<sub>2</sub>)

A breath-by-breath automatic portable gas analysis system (Cosmed K5, Italy) was used to measure the maximal oxygen utilization capacity and heart rate of the athletes. For this purpose, the athletes were asked to run at a constant speed of 5.0 km/h on the treadmill for 2 minutes, and then to run at an increasing speed of 0.016 km/h every second in accordance with the protocol. The athletes'

running was monitored in accordance with the test completion criteria used in treadmill protocols for aerobic capacity and power measurements.

The simultaneous observance of three of the following criteria was accepted as an indication that the maximal oxygen utilization capacity had been reached and the test was terminated. Athlete's perception of fatigue on the original Borg scale rated as 17 or above and the athlete declaring to be exhausted, oxygen consumption no longer rising despite an increase in workload, ratio of carbon dioxide production to oxygen consumption (RQ) value reaching 1.15 and above, having a heart rate of 85% or more of the maximal heart rate, no increase in heart rate despite increased workload. The values measured in the last 30 seconds of aerobic capacity obtained with the automatic portable gas analysis program were averaged out and the ratios to the athletes' body weight were calculated (19). In gas analysis, minute ventilation (VE), oxygen volume per minute (VO<sub>2</sub>), and carbon dioxide produced per minute (VCO<sub>2</sub>) were directly measured and recorded.

### 2.3. Statistical Analysis

Statistical analysis of the data was performed using IBM SPSS Version 21 (IBM Corp. Released 2012, Armonk, NY). The normal distribution of the data was assessed visually and with the Shapiro-Wilk test. The association between Max VO<sub>2</sub>, VE, VO<sub>2</sub>, and VCO<sub>2</sub> values derived from the research cohort and respiratory parameters was examined using linear regression analysis. Statistical significance was determined at  $p < 0.05$ .

### 3. Results

The details of the statistical analyzes of the Max VO<sub>2</sub>, VE, VO<sub>2</sub> and VCO<sub>2</sub> parameters obtained from the research group are given in tabular format below.

According to Table 2, the parameters obtained from the research group show a high and significant relationship with MaxVO<sub>2</sub>/kg ( $R=.715$ ,  $R^2=.511$ ,  $p<0.05$ ). The mentioned variables together explain 51% of the total variance in Max VO<sub>2</sub>/kg. According to the standardized regression coefficient ( $\beta$ ), Mid-Axilla circumference, MEP and Inspiratory Subcostal circumference values have a significant effect on MaxVO<sub>2</sub>, while the other predictor variables do not seem to have a significant effect on MaxVO<sub>2</sub>. When the bilateral and partial correlations between the predictor variables and MaxVO<sub>2</sub> were examined, a negative correlation was observed between MIP, mid-axilla and axilla circumference measurements on inspiration and expiration and mid-subcostal and subcostal circumference measurements on inspiration and expiration. A positive relationship was determined between MEP and MVV values.

**Table 2.** Regression analysis results regarding MaxVO<sub>2</sub>/kg ( $X=58.52\pm 10.74$  ml/kg/min) prediction of the parameters obtained from the study group.

Characteristics	X	Sd	B	SH	$\beta$	T	p	Zero-order	Partial
(Constant)			131.529	17.495		7.518	0		
MIP (Cm/H <sub>2</sub> O)	99.08	29.7	-0.098	0.065	-0.271	-1.504	0.143	-0.092	-0.265
MEP (Cm/H <sub>2</sub> O)	130.95	42.82	0.148	0.048	0.59	3.091	0.004	0.108	0.491
Mid-Axilla Circumference (Cm)	91.4	10.72	-3.498	1.642	-3.489	-2.13	0.041	-0.42	-0.363
Axilla Circumference On Inspiration (Cm)	95.2	10.216	0.511	0.932	0.486	0.548	0.588	-0.405	0.1



Subcostal Circumference On Inspiration (Cm)	82.95	9.462	-3.838	1.571	-	-2.443	.021	.419	-.407
					1.361				
Subcostal Circumference On Expiration (Cm)	76.63	10.505	1.849	2.168	.728	.853	.400	.524	.154
MVV	135.63	38.39	.124	.115	.178	1.073	.292	.534	.192
$F_{(9,30)}=4.552$			$P=.001$						
$R=.760$			$R^2=.577$						

MIP: Maximum inspiratory pressure, MEP: Maximum expiratory pressure, MVV: Maximum voluntary ventilation. VE: Minute Ventilation.

Table 4 shows that the parameters obtained from the research group show a high and significant relationship with VO<sub>2</sub> ( $R=.814$ ,  $R^2=.663$ ,  $p<0.05$ ). The mentioned variables together explain 66% of the total variance in VO<sub>2</sub>. According to the standardized regression coefficient ( $\beta$ ), the values of MEP and Subcostal circumference on inspiration have a significant effect on VO<sub>2</sub>, while the other predictor variables do not seem to have a significant effect on VO<sub>2</sub>. When the bilateral and partial correlations between predictor variables and VO<sub>2</sub> were examined, low-level correlations were found between MIP and VO<sub>2</sub>, and moderate and positive correlations with other parameters.

**Table 4.** Regression analysis results regarding VO<sub>2</sub> ( $X_{ort}=3877.52\pm 868.47$  ml) prediction of the parameters obtained from the study group.

Characteristics	X	SD	B	SH	B	T	p	Zero-Order	Partial
(Constant)			1716.990	1173.112		1.464	.154		
MIP (Cm/H <sub>2</sub> O)	99.08	29.70	-7.307	4.376	-.250	-1.670	.105	.347	-.292
MEP (Cm/H <sub>2</sub> O)	130.95	42.82	11.606	3.210	.572	3.616	.001	.624	.551
Mid-Axilla Circumference (Cm)	91.40	10.720	-187.015	110.081	-	-1.699	.100	.597	-.296
					2.308				
Axilla Circumference On Inspiration (Cm)	95.20	10.216	44.433	62.518	.523	.711	.483	.607	.129
Axilla Circumference On Expiration (Cm)	89.13	10.827	129.642	88.048	1.616	1.472	.151	.602	.260
Mid-Subcostal Circumference (Cm)	78.82	10.454	76.020	71.878	.915	1.058	.299	.621	.190
Subcostal Circumference On Inspiration (Cm)	82.95	9.462	-81.135	45.639	-.884	-1.778	.086	.562	-.309
Subcostal Circumference On Expiration (Cm)	76.63	10.505	34.126	62.958	.413	.542	.592	.625	.098

MVV 135.63 38.39 5.857 3.350 .259 1.748 .091 .584 .304

$F_{(9,30)}=6.562$

$P=.000$

$R=.814$

$R^2=.663$

MIP: Maximum Inspiratory Pressure, MEP: Maximum Expiratory Pressure, MVV: Maximum Voluntary Ventilation.

In Table 5, it is seen that the parameters obtained from the research group show a high and significant relationship with VCO<sub>2</sub> ( $R=.802$ ,  $R^2=.643$ ,  $p<0.05$ ). The mentioned variables together explain 64% of the total variance in VCO<sub>2</sub>. According to the standardized regression coefficient ( $\beta$ ), the values of MEP and Inspiratory Subcostal circumference measurement have a significant effect on VCO<sub>2</sub>, while other the predictor variables do not seem to have a significant effect on VCO<sub>2</sub>. When the bilateral and partial correlations between the predictor variables and VCO<sub>2</sub> were examined, low level correlations were found between MIP and VCO<sub>2</sub>, and moderate and positive correlations with other parameters.

**Table 5.** Regression analysis results regarding VCO<sub>2</sub> ( $X_{ort}=4301.27\pm 1001.07$  ml) prediction of the parameters obtained from the study group.

Characteristics	X	SD	B	SH	B	T	p	Zero-Order	Partial
(Constant)			2314.699	1392.589		1.662	.107		
MIP (Cm/H <sub>2</sub> O)	99.08	29.70	-10.586	5.195	-.314	-2.038	.050	.279	-.349
MEP (Cm/H <sub>2</sub> O)	130.95	42.82	14.358	3.810	.614	3.769	.001	.590	.567
Mid-Axilla Circumference (Cm)	91.40	10.720	-193.217	130.677	-	-1.479	.150	.588	-.261
Axilla Circumference On Inspiration (Cm)	95.20	10.216	17.688	74.215	.181	.238	.813	.590	.043
Axilla Circumference On Expiration (Cm)	89.13	10.827	154.760	104.521	1.674	1.481	.149	.593	.261
Mid-Subcostal Circumference (Cm)	78.82	10.454	116.701	85.326	1.219	1.368	.182	.614	.242
Subcostal Circumference On Inspiration (Cm)	82.95	9.462	-104.461	54.177	-.987	-1.928	.043	.547	-.332
Subcostal Circumference On Expiration (Cm)	76.63	10.505	28.444	74.737	.299	.381	.706	.618	.069
MVV	135.63	38.39	4.590	3.977	.176	1.154	.257	.527	.206
$F_{(9,30)}=5.996$									
$R=.802$									
$P=.000$									
$R^2=.643$									

MIP: Maximum Inspiratory Pressure, MEP: Maximum Expiratory Pressure, MVV: Maximum Voluntary Ventilation.

#### 4. Discussion

The objective of this study was to investigate the influence of athletes' respiratory muscle strength, evaluated through maximal inspiratory (MEP) and expiratory pressure (MEP), on aerobic endurance, as delineated by maximal oxygen consumption (Max VO<sub>2</sub>) kinetics. 16% of oxygen intake during exercise is used by the respiratory muscles. Taking this into consideration, the effect of the respiratory muscles on performance is non-negligible (20). Inspiration is an active process both at rest and in exercise. The diaphragm is the primary inspiratory muscle, and its mitochondrial volume density, oxidative capacity and aerobic capacity of muscle fibers are four times higher than most other skeletal muscles. The other important inspiratory muscles are the intercostal muscles. The diaphragm or intercostals alone provide adequate breathing in the resting state, while the efficiency of the diaphragm decreases during vigorous exercise; the scalene muscles, pectoralis minor and sternocleidomastoid muscles are gradually activated to assist inspiration (20). During resting breathing, expiration is passive as the rib cage and lungs tend to return to their original state due to their flexible structure. Intercostal muscles that are activated during exercise are responsible for forced expiration. When ventilation is increased, lung contraction also increases as a result of active contractions of the expiratory muscles that decrease the intrathoracic volume (21).

Upon analyzing the findings of our study, we noted a negative correlation between Max VO<sub>2</sub> and measurements of circumference at the mid-axilla and axilla during both inspiration and expiration, as well as at the mid-subcostal and subcostal regions during inspiration and expiration. Conversely, positive correlations were observed between maximal expiratory pressure (MEP) and maximal voluntary ventilation (MVV). These findings imply an enhanced ventilatory response during exercise, wherein greater expiratory muscle strength and maximal voluntary ventilation capacity lead to increased respiratory frequency. Consequently, this facilitates the rapid removal of carbon dioxide and enhanced uptake of oxygen during physical exertion.

In the literature, Klusiewicz (2014) could not find a correlation between the MIP value and absolute or relative max VO<sub>2</sub> values in male athletes, but he found a correlation between the MIP value and absolute or relative max VO<sub>2</sub> values in female athletes. In our study, no significant relationship could be found between relative maxVO<sub>2</sub> and MIP measurement results, which suggests that the athletes in our study reached their Max VO<sub>2</sub> value before reaching their maximum inspiratory muscle strength potential (22).

Previous studies in the literature mostly explain the effect of respiratory muscle strengthening training on MaxVO<sub>2</sub>. For example, Lomax et al. (2011) reported that respiratory muscle training and warm-up of the respiratory muscles (at 40% of the maximal inspiratory muscle strength) on 12 male football players consisting of two groups increased their Yo-Yo test performance compared to the control group (23). Volianitis et al. (2001) reported in a study they conducted on female rowing athletes that the athletes' maxVO<sub>2</sub> value after respiratory muscle warm-up exercise performed with branch-specific general warm-up was higher than that of the experimental group (24). In contrast, Amonette and Dupler (2002) reported in a study that breathing exercises did not cause an improvement in maxVO<sub>2</sub> capacity (25). In another study conducted on young football players, it was reported that there was no significant change in maxVO<sub>2</sub> values after a four-week respiratory muscle training program (26). Romer et al. (2002) found that there was no significant change in the maxVO<sub>2</sub> values of the subjects after respiratory muscle training (9).

During high-intensity endurance exercise, excessive metabolic CO<sub>2</sub> production can only be removed by increased ventilation. If respiratory muscle strength or endurance remains below the increased demand for ventilation, tissue and blood CO<sub>2</sub> will increase, causing metabolic acidosis and thus failure of both skeletal and respiratory musculature, which signifies the importance of expiratory muscle strength. We determined that the moderate positive correlation findings between MEP and VCO<sub>2</sub> in our study prove the importance of expiratory muscle strength. In our study, it was determined that the values of subcostal circumference measurement in MEP and on inspiration had a significant effect on VE. In line with this result, it can be predicted that since the amount of air entering the lungs per minute will increase with the development of respiratory muscles, sports performance will also increase positively.

Efficient utilization of respiratory muscles holds paramount importance during prolonged aerobic activities. It is postulated that enhanced economy in the functioning of respiratory musculature correlates with improved exercise performance (27). Thus, it becomes imperative to augment respiratory muscle strength through training to bolster overall exercise capacity. Endurance training is believed to defer fatigue onset in respiratory muscles while concurrently enhancing oxygen utilization efficiency. With the advancement of respiratory muscle development, it is anticipated that the volume of air intake will rise, consequently leading to a positive augmentation in sports performance (3).

The practical applications of our study's findings hold significance for athletes, coaches, and sports scientists alike. Incorporating specific respiratory muscle training into athletes' conditioning regimens can improve their respiratory muscle strength, thereby enhancing their overall aerobic capacity and endurance. This may involve exercises such as inspiratory muscle training (IMT) or expiratory muscle training (EMT) targeting the muscles involved in respiration. Moreover, understanding the relationship between respiratory muscle strength and aerobic performance allows for more effective performance optimization strategies. Coaches and trainers can use this knowledge to develop individualized training plans that address athletes' specific respiratory needs, ultimately maximizing their athletic potential. Additionally, strengthening respiratory muscles not only improves performance but also contributes to injury prevention. Enhanced respiratory muscle strength can help athletes maintain proper breathing mechanics during strenuous exercise, reducing the risk of fatigue-related injuries and respiratory distress. Lastly, regular assessment of respiratory muscle strength can serve as a valuable tool for monitoring athletes' progress and identifying areas for improvement. Integrating objective measures, such as maximal inspiratory and expiratory pressure assessments, into routine performance evaluations enables coaches and sports scientists to track changes in respiratory function over time and adjust training protocols accordingly.

Despite the valuable insights gained from this study, several limitations should be acknowledged. First, the sample size in this study may limit the generalizability of the findings to broader athlete populations. Future research with larger and more diverse samples is needed to validate the observed associations across different sports and athletic levels. Second, the cross-sectional nature of this study precludes establishing causality between respiratory muscle strength and aerobic endurance. Longitudinal studies are warranted to elucidate the temporal relationships between these variables and better understand the effects of respiratory muscle training over time. Third, the laboratory-based setting of this study may not fully replicate the real-world conditions in which athletes train and compete. The transferability of the findings to actual sporting environments warrants consideration, as performance outcomes may be influenced by additional factors not captured in controlled laboratory settings. Acknowledging these limitations provides valuable insights into the scope and interpretation of the study findings. Addressing these limitations in future research endeavors will contribute to a more comprehensive understanding of the complex interplay between respiratory muscle strength and athletic performance.

## 5. Conclusions

Our investigation elucidates the substantial influence of respiratory muscle strength, notably measured through maximal inspiratory and MEP, on various physiological parameters related to aerobic endurance among athletes. Specifically, our results reveal significant associations between MEP and inspiratory diaphragmatic circumference values with VE, VO<sub>2</sub>, and VCO<sub>2</sub>. Moreover, the measured values of diaphragmatic circumference during inspiration and MEP significantly impact Max VO<sub>2</sub>. These findings underscore the pivotal role of respiratory muscle strength in shaping athletes' aerobic performance profiles. Such insights provide valuable implications for tailored training strategies aimed at optimizing athletes' respiratory function and overall endurance capacity. Lastly, the practical applications of our study underscore the importance of integrating respiratory muscle training into athletes' preparation and conditioning programs. By optimizing respiratory function, practitioners can enhance athletes' aerobic performance, reduce the risk of injury, and ultimately support their pursuit of athletic excellence.

**Author Contributions:** Conceptualization, G.D, B.K., V.O.Ç., H. İ. C., M.R., S.V.; methodology, G.D, H. İ. C., M.R., S.V; formal analysis, H. İ. C., M.R., S.V; investigation, G.D, B.K., V.O.Ç.; writing—original draft preparation, G.D, B.K., V.O.Ç., H. İ. C., M.R., S.V; writing—review and editing, G.D, B.K., V.O.Ç., H. İ. C., M.R., S.V; supervision, H. İ. C., S.V; funding acquisition, M.R., S.V. All authors have read and agreed to the published version of the manuscript.

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**Data Availability Statement:** The data that support the findings of this study are available on request from the corresponding author.

**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study

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**Conflicts of Interest:** The authors declare no conflicts of interest.

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