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Correlation Between Dynamic Inspiratory Muscle Strength and Some Variables Associated with Aerobic Capacity

Dinamik İnspiratuar Kas Kuvveti ile Aerobik Kapasiteyi Etkileyen Bazı Değişkenlerin İlişkisi

Research Article / Araştırma Makalesi

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Abstract

The aim of this study was to investigate the relationship between dynamic inspiratory muscle strength (IMS) and body composition, peak oxygen consumption (VO_{2peak}), running economy (RE), and pulmonary function test variables. A total of 30 students (8 female and 22 male) (age=21.83±2.09years) from the Faculty of Sport Sciences voluntarily participated in this study. Body composition (with bioelectrical impedance analysis), dynamic inspiratory muscle strength (S-index), and tests of pulmonary function, VO_{2peak}, and RE were performed. VO_{2peak} and RE tests were measured using an ergo-spirometry system. The VO_{2peak} test started with a 5-min warm-up on the treadmill at a 1% constant incline at 6 km/h speed. The test began at an 8 km/h speed, without a break, and persisted by increasing the speed by 1 km/h every 2 minutes until exhaustion. RE was taken on a treadmill with 6-minute tests at a constant speed at 70% and 80% of VO_{2peak}. S-index indicated a significant positive correlation with body composition variables, lean body mass (r=0.661), total body water (r=0.667), and body mass index (r=0.602) ($p<0.05$). No significant correlation was found between the S-index and VO_2 (ml·kg^{-1}·min^{-1}) taken by RE tests ($p>0.05$). However, a significantly moderate positive correlation was determined between S-index and VO_{2peak} (ml·kg^{-1}·min^{-1}) (r=0.380) ($p<0.05$). Regarding the pulmonary function test, forced vital capacity (r= 0.634), forced expiratory volume in the first second (r=0.600), peak expiratory flow (r=0.768), and maximum voluntary ventilation (r=0.770) indicated a significant positive correlation with S-index ($p<0.05$). In conclusion, dynamic inspiratory muscle strength was found to be significantly related to lean body mass and some pulmonary function variables. As a result of VO_{2peak} and RE, which are critical variables of aerobic performance, it is thought that dynamic inspiratory muscle strength may be relevant to oxygen consumption at maximal exercise rather than submaximal exercise.

Keywords: Respiratory muscle strength, VO2 peak, Running economy, Pulmonary function test

Öz

Bu çalışmanın amacı, dinamik inspiratuar kas kuvveti ile vücut kompozisyonu, zirve oksijen tüketimi (VO_{2zirve}), koşu ekonomisi (KE) ve solunum fonksiyon testi değişkenleri arasındaki ilişkinin incelenmesidir. Çalışmaya Spor Bilimleri Fakültesi öğrencisi olan toplam 30 öğrenci (8 kadın ve 22 erkek) (yaş=21.83±2.09 yıl) gönüllü olarak katılmıştır. Katılımcılara vücut kompozisyonu ölçümleri (biyoelektrik impedans analizi ile), dinamik inspiratuar kas kuvveti (S-indeksi), solunum fonksiyon, VO_{2zirve} ve KE testleri uygulanmıştır. VO_{2zirve} ve KE testleri ergospirometri sistemi gaz analizörü ile ölçülmüştür. VO_{2zirve} testi, koşu bandında %1 sabit eğimde 6 km/saat hızda 5 dakikalık ısınma ile başlamıştır. Ardından ara vermeden 8 km/saat hızla test başlamış ve her 2 dakikada bir 1 km/saat hız artırılarak katılımcı tükenene kadar teste devam edilmiştir. KE, VO_{2zirve} değerinin %70 ve %80'ine karşılık gelen sabit hızda 6 dakikalık koşu bandı testleri ile ölçülmüştür. S-indeks, vücut kompozisyonu değişkenlerinden yağsız vücut kütlesi (r=0.661), toplam vücut suyu (r=0.667) ve vücut kütle indeksi (r=0.602) ile pozitif anlamlı ilişki göstermiştir ($p<0.05$). S-indeks ile KE testlerinden belirlenen VO_2 (ml·kg^{-1}·dk^{-1}) değerleri arasında anlamlı ilişki bulunmamıştır ($p>0.05$), ancak VO_{2zirve} (ml·kg^{-1}·dk^{-1}) ile arasında orta düzeyde anlamlı pozitif ilişki tespit edilmiştir (r=0,380) ($p<0,05$). Solunum fonksiyon testlerinden ise zorlu vital kapasite (r= 0.634), birinci saniyedeki zorlu ekspiratuar hacim (r=0.600), zirve ekspiratuar akım (r=0.768) ve maksimum istemli ventilasyon (r=0.770) değerleri, S-indeks ile pozitif anlamlı ilişki göstermiştir ($p<0.05$). Sonuç olarak, dinamik inspiratuar kas kuvvetinin, yağsız vücut kütlesi ve bazı solunum fonksiyon değişkenleri ile anlamlı ilişkisi olduğu görülmüştür. Aerobik performansın önemli göstergelerinden olan VO_{2zirve} ve KE sonuçlarına göre ise dinamik inspiratuar kas kuvvetinin submaksimal egzersizlerden ziyade maksimal egzersizdeki oksijen tüketimiyle ilişkili olduğu düşünülmektedir.

Anahtar Kelimeler: Solunum kas kuvveti, VO2 zirve, Koşu ekonomisi, Solunum fonksiyon test

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Introduction

Aerobic endurance performance can be attributed to three main variables: maximal oxygen uptake, lactate threshold, and exercise economy (Helgerud et al., 2007). The most critical one in deciding the achievement of aerobic endurance performance is likely VO_{2max} (Helgerud et al., 2007). However, VO_{2max} is not a favorable performance estimator at each condition, for instance, for runners who have similar VO_{2max} levels (Bassett & Howley, 2000). Running economy (RE) is a more suitable performance estimator than VO_{2max} in runners who have similar VO_{2max} values (Barnes & Kilding, 2015; Fletcher, Esau, & MacIntosh, 2009; Saunders, Pyne, Telford, & Hawley, 2004). RE is the steady-state oxygen consumption (VO_2) at a constant submaximal running velocity and represents the energy demand at that constant velocity of submaximal exercise. At the same exercise speed, runners with higher RE consume less oxygen than those with lower RE (Barnes & Kilding, 2015; Saunders et al., 2004). Despite the importance of RE for aerobic exercise performance, there is neither an experimental study to test the effect of inspiratory muscle training on RE nor a correlation study to test the relations between IMS and RE, to the best of our knowledge. On the other hand, one of the training methods used to improve aerobic performance is respiratory muscle training (RMT) (de Sousa et al., 2021; Koç & Saritas, 2019; Markov, Spengler, KnoÈpfli-Lenzin, Stuessi, & Boutellier, 2001). For instance, an 8-week RMT increased VO_{2max} in taekwondo athletes in the study of Koç and Saritas (2019). While Volianitis et al. (2001) found RMT enhanced rowing performance on the 5000-m trial in competitive rowers, Stuessi, Spengler, KnoÈpfli-Lenzin, Markov, and Boutellier (2001) reported that RMT improved cycling endurance in sedentary subjects. There are mainly training studies resulting in VO_{2max} improved by RMT, but studies investigating the correlation between VO_{2max} and IMS are limited. For instance, Klusiewicz (2008) found a significant positive correlation between IMS and VO_{2max} in female athletes. Gök, Koç, Macit, Arslantürk, and Coşkun (2024) found a positively significant moderate relationship between dynamic IMS and estimated VO_{2max} in physically active university students, but Deliceoğlu, Kabak, et al. (2024) and McConnell, Caine, and Sharpe (1997) did not find a significant relation in trained athletes. The lack of studies on RE and the contradictory and limited number of studies on the relationship between VO_{2max} and IMS necessitate the examination of the relationship between these two factors, RE and VO2max, with IMS.

One of the sensitive and widespread ways of determining inspiratory muscle strength is the test of maximal inspiratory pressure (MIP) (Pessoa et al., 2014; Schoser et al., 2017). MIP is a noninvasive test that is applied with powerful inspiration resisting an occluded mouthpiece (Pessoa et al., 2014). MIP is mainly used to test inspiratory muscle strength, which is a traditional spirometry measurement. However, spirometry tests have been mostly used for medical reasons, with specific rules applied by only medical professionals. To assess MIP in sports environments, there is a current option called the S-index test generated by POWERbreathe (POWERbreathe International Ltd., Southam, UK) (Kowalski & Klusiewicz, 2023). The S-Index is also a noninvasive and easy test, but it evaluates IMS dynamically (Areias, Santiago, Teixeira, & Reis, 2020). MIP is established on static effort, while the S-index test is based on dynamic maneuvers. Therefore, the S-index test is recommended for sports settings (Kowalski & Klusiewicz, 2023).

Body composition (Nalbant & Özer, 2018; Sharma, Kamal, & Chawla, 2016) and pulmonary function (Campoi et al., 2019; Fatemi, Shakerian, Ghanbarzade, Habibi, & Fathi, 2012) are other variables related to aerobic performance. It is well known that aerobic power is affected by body composition, especially body fat has an impact on cardiorespiratory functions, and there is an inverse relationship between aerobic endurance and body fat (Nalbant & Özer, 2018; Sharma et al., 2016). Fatemi et al. (2012) concluded that pulmonary functions are associated with VO_{2max} and can have a restrictive effect on aerobic capacity. Campoi et al. (2019) reported that VO_{2max} may directly affect pulmonary capacity. It is noted that FEV_1 (forced expiratory volume in one second) and FVC (forced vital capacity) raised with the improvement of VO_{2max}, and there may be a direct influence on inspiratory muscle strength (IMS) (Campoi et al., 2019). However, the study results investigating these two variables, body composition and pulmonary function, with regard to the relationship with IMS are not constant (Bairapareddy et al., 2021; Gök et al., 2024; Hackett & Sabag, 2021; Hulzebos, Takken, Reijneveld, Mulder, & Bongers, 2018; Ozmen, Gunes, Ucar, Dogan, & Gafuroglu, 2017). Therefore, the aim of this study is to examine the relationship of dynamic inspiratory muscle strength with aerobic performance-related variables such as body composition and pulmonary function, and especially VO_{2peak} and RE, which are the main determinants of aerobic performance. While we hypothesize that we will likely find a substantial positive correlation between IMS and VO_{2peak}, we are unable to mention the relationship between IMS and RE because of lack of research on it.

Method

Study Design

This research is a correlational study. Before the main test days, the tests were introduced, and participants performed trials for S-index and spirometry tests. Body composition and resting heart rate were measured before the tests on the test day. Then, dynamic IMS measurement, pulmonary function test, and VO_{2peak} test were performed. RE tests were performed at least 24 hours after the VO_{2peak} test. Participants were asked not to participate in physical activity on the recovery day between VO_{2peak} and RE tests. The tests were performed at the same time of day. The research design is presented in Figure 1.

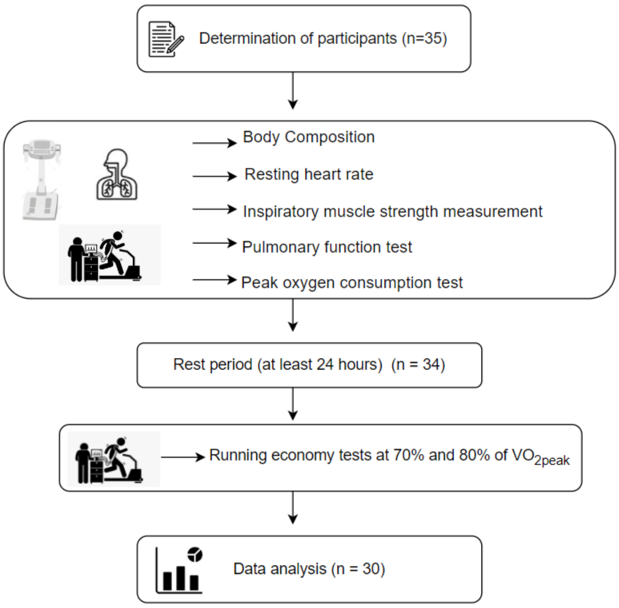

Figure 1. Study protocol

Participants

A priori participant number was decided by using the G Power (G*Power 3.1.9.7) power analysis program. It was evaluated with a significance level of 0.05, 80% statistical power, and 0.50 effect size (Gök et al., 2024), and the number of participants was found to be 29.

Thirty-five university students from a Faculty of Sports Sciences, who had no chronic respiratory or cardiovascular diseases, voluntarily participated in this study. However, the data of five students were not included in the analyses since they did not complete all the test procedures. Volunteers were randomly selected from untrained individuals who were not competitive athletes. Those with a respiratory infection within the last four weeks were not included in the study. The study was completed with 30 students (age=21.83±2.09 years, body height=169.00±8.10 cm, body weight=66.71±10.21 kg), 22 male and 8 female. Before starting data collection, each participant filled out a written informed consent form after getting brief information about the study.

Data Collection Instruments

Body Composition

While body height was determined with a Seca stadiometer (Seca 213, Hamburg, Germany), body weight and body composition variables were determined with the Jawon Segmental body composition analyzer Avis 333 Plus (Korea). Participants took part in the tests with sportswear, and the clothing weight was recorded as 0.5 kilograms (kg) into the device. Body weight, percent body fat (PBF), lean body mass (LBM), total body water (TBW), and body mass index (BMI) values were obtained with bioelectrical impedance analysis.

Heart Rate

Heart rate was determined with the Polar Team2 System (Finland) at rest and during the VO_{2peak} test. Resting heart rates were recorded for 5 minutes in the supine position without talking using the Elite HRV (Elite Hrv Inc. USA) smartphone application. The results were transmitted to the computer and read via the Kubios HRV (The MathWorks, Inc. USA) application. The oxygen saturations at rest were measured on the left index finger with a pulse oximeter (JPD-500E Model).

Pulmonary Function

Pulmonary function variables were estimated using an MIR brand MiniSpir model spirometer (Rome, Italy) in a sitting position, and the results were recorded on the computer with the Winspiro PRO 8.1 program. A new cardboard mouthpiece of the spirometer was used for each participant before testing. A nose clip was used during the tests. Slow and forced vital capacity measurements were applied according to the standards of the American Thoracic Society and the European Respiratory Society (Graham et al., 2019). At least three trials were taken at 2-minute intervals, and the best value was evaluated for analysis (Tenório et al., 2012). Maximum voluntary ventilation was determined by breathing as fast and deep as possible for 12 seconds (Tenório et al., 2012). The variables of forced vital capacity (FVC) forced expiratory volume in one second (FEV_1), FEV_1/FVC ratio (FEV_1/FVC), peak expiratory flow (PEF), forced expiratory flow between 25%–75% of vital capacity ($FEF_{25-75\%}$), vital capacity (VC), and maximal voluntary ventilation (MVV) obtained from pulmonary function tests were used in the analyses.

Dynamic Inspiratory Muscle Strength Measurement

Dynamic inspiratory muscle strength (S-index) was measured with a POWERbreathe K5 (HaB International Ltd, England) device with the participant in a sitting position and with their nose closed with a nose clip. The measurement was taken with 10 consecutive repetitions (P. E. Silva et al., 2018). The best value measured was recorded as the score (Minahan et al., 2015; R. L. C. Silva, Hall, & Maior, 2019). The participants were instructed and motivated by the same researcher during the assessments to show maximum performance (P. E. Silva et al., 2018; R. L. C. Silva et al., 2019).

Peak Oxygen Consumption

Peak oxygen consumption (VO_{2peak}) was determined on a treadmill in the laboratory with a Jaeger brand Masterscreen CPX model ergo- spirometer system (Germany) gas analyzer. Before starting the test, the device calibration was appropriately completed according to the manufacturer's instructions. To determine VO_{2peak}, a running test was performed on a treadmill at a constant incline with an increasing speed protocol. This test, which was implemented using a gradually increasing workload protocol, started with a 5-minute warm-up at a 6 km/h speed at a constant 1% slope. After warm-up, the test protocol was started at 8 km/h speed without a break, and the speed was increased by 1 km/h every 2 minutes until the participant was exhausted (Archiza et al., 2018; Castagna, Impellizzeri, Chamari, Carlomagno, & Rampinini, 2006; Colosio, Pedrinolla, Da Lozzo, & Pogliaghi, 2018). Since the tests applied in the studies of Colosio et al. (2018) and Castagna et al. (2006) were conducted on groups of athletes, we made some changes in the workload increase in our study, adapting from the studies of Colosio et al. (2018) and Castagna et al. (2006). For this test conducted in the laboratory, the treadmill incline was kept constant at 1% to correspond to wind resistance (Jones & Doust, 1996). The 30-second VO_2 averages of the last 2 minutes of the treadmill test were evaluated, and the highest one was used as the VO_{2peak} for the analyses (Keiller & Gordon, 2018). The maximum HR value of 10 seconds in the last 2 minutes was considered as the HR_{peak} (Colosio et al., 2018; Keiller & Gordon, 2018). The following criteria were evaluated as the termination criteria of the VO_{2peak} test.

- There is no increase in VO_2 despite increased workload (plateau)
- The heart rate at the end of the test reaches within ±10 beats of the theoretical maximum HR (220 - age),
- Respiratory exchange ratio (VCO_2/VO_2) exceeds 1.10,
- Rating of perceived exertion **(**RPE) score exceeds 17 (Castagna et al., 2006; Faulkner, Mauger, Woolley, & Lambrick, 2015).

Running Economy

Running Economy (RE) measurements were performed in the laboratory with the same devices used in the VO_{2peak} test. Running speeds were determined using peak oxygen consumption data. A previous study investigated the alterations in RE at various intensities and concluded that RE evaluated at high-intensity exercise is impacted more than at low-intensity exercise. Regarding the previous studies and their experiences, the authors tested RE at three intensities, 70%, 80%, and 90% VO_{2max}, since they assumed 70% VO_{2max} as below the lactate threshold, 80% VO_{2max} as close to the lactate threshold, and 90% VO_{2max} as above the lactate threshold (Chen, Nosaka, Lin, Chen, & Wu, 2009). Therefore, in our study, we tested RE with a 6-minute treadmill test at a constant speed with an intensity of 70% and 80% of VO_{2peak} (Chen et al., 2009; Weston, Mbambo, & Myburgh, 2000). Participants began the test with a 4-minute warm-up at approximately 50% VO_{2peak} (Lundby et al., 2017). After the warm-up, we randomly applied RE tests at 70% and 80% of VO_{2peak} for each individual. In both RE tests, performed in random order, RPE was recorded in the last 20 seconds of the test (Chen et al., 2009). A 5-minute passive rest was given between running tests at two different intensities (W. A. Silva, de Lira, Vancini, & Andrade, 2018; Weston et al., 2000). The average of the last 1-minute values recorded by the Jaeger brand Masterscreen CPX model ergo-spirometer system (Germany) gas analyzer was used in the analyses (Chen et al., 2009; Weston et al., 2000). The heart rate average of the last 1 minute was recorded as the heart rate value of the RE tests ($HR_{70\%}$ and $HR_{80\%}$). VO_2 in the last 1 minute was taken as $ml \cdot kg^{-1} \cdot min^{-1}$ to be used in the analyses and was also normalized with respect to the 0.66 power of the body weight (Weston et al., 2000). Thus, the amount of oxygen consumed in the RE tests was evaluated in the analyses as $ml \cdot kg^{-1} \cdot min^{-1}$ and $ml \cdot kg^{-0.66} \cdot min^{-1}$. $HR_{70\%}$, $HR_{80\%}$, $RPE_{70\%}$, and $RPE_{80\%}$ values were also included in the analyses as RE test variables.

Rating of Perceived Exertion

Rate of Perceived Exertion (RPE) was assessed with the Borg scale (6-20). For the tests conducted with the treadmill, we placed the Borg scale where the participants could easily see it throughout the tests. RPE was recorded every two minutes of the VO_{2peak} test and in the last 20 seconds of the RE tests.

Data Analysis

IBM SPSS 23.0 statistical package program was used for data analyses. Mean and standard deviations were given to represent descriptive statistics. The normal distribution of the variables was checked with the Shapiro-Wilk test. While Pearson correlation analysis was used for the variables with satisfied normality assumption, Spearman correlation analysis was used for those unsatisfied with the normality assumption. The significance level was accepted as $p<0.05$. The power of correlations was categorized as trivial (r is under 0.1), small (r is higher than 0.1 and up to 0.3), moderate (r is higher than 0.3 and up to 0.4), strong (r is higher than 0.5 and up to 0.7), very strong (r is higher than 0.7 and up to 0.9), nearly perfect (r is higher than 0.9), and perfect (r is equal to 1.0) (Hackett & Sabag, 2021; Stone, Moir, Glaister, & Sanders, 2002).

Ethics Statement

Ethical approval was obtained from the Clinical Research Ethics Committee of Erciyes University Faculty of Medicine on 22.09.2021 with number 2021/606.

Results

A total of 30 students, 22 male (age=21.82±2.24 years, body height=171.14±6.62 cm, body weight=70.01±6.07 kg, S-index=154.44±17.43 cmH_2O) and 8 female (age=21.88±1.73 years, body height=163.13±9.33 cm, body weight=57.63±13.90 kg, S-index=100.28±24.58 cmH_2O) students participated in this study.

Descriptive statistics of body composition variables and the relationship between the S-index and these variables are presented in Table 1. The S-index is found to be strongly positively correlated with the variables LMB (kg) (r=0.661), TBW (kg) (r=0.667), and BMI (kg/m²) (r= 0.602) ($p<0.05$) (Table 1).

Table 1. Descriptive statistics of body composition and correlations between the variables and dynamic IMS

Variables	Mean ± SD	S-index (cmH_2O)	
		r	p
PBF (%)	20.89 ± 3.57	-0.340	0.066
LBM (kg)	52.48 ± 7.76	**0.661**	**<0.001**
TBW (kg)	37.78 ± 5.58	**0.667**	**<0.001**
BMI (kg/m²)	23.26 ± 2.71	**0.602**	**<0.001**
HR_{rest} (bpm)	76.73 ± 16.45	-0.077	0.686
SpO_2 (%)	97.20 ± 1.86	-0.156	0.410
S-index (cmH_2O)	139.99 ± 30.97	1	

PBF (%): Percent body fat, LBM (kg): Lean body mass, TBW (kg): Total body water, BMI (kg/m²): Body mass index, HRrest (bpm): Heart rate at rest, SpO_2 (%): Pulse oximetry oxygen saturation.

VO_{2peak} test variables and results are given in Table 2. The findings indicate that there is a moderate positive correlation between the S-index and VO_{2peak} (ml·kg^{-1}·min^{-1}) (r=0.380) ($p<0.05$), but there is no significant correlation with the other two variables (HR_{peak} and RPE_{peak}) ($p>0.05$) (Table 2).

Table 2. Descriptive statistics of VO_{2peak} test variables and correlations between the variables and dynamic IMS

Variables	Mean ± SD	S-index (cmH_2O)	
		r	p
VO_{2peak} (ml·kg^{-1}·min^{-1})	44.49 ± 4.45	**0.380**	**0.038**
HR_{peak} (bpm)	189.53± 7.74	-0.153	0.419
RPE_{peak}	18.33 ± 1.24	-0.032	0.866

VO_{2peak} (ml·kg^{-1}·min^{-1}): Peak oxygen consumption, HR_{peak} (bpm): Heart rate, RPE_{peak}: Rating of perceived exertion.

Table 3. Descriptive statistics of RE test results and correlations between the variables and dynamic IMS

Variables	Mean ± SD	S-index (cmH_2O)	
		r	p
$VO_{2Economy70\%}$	33.41 ± 3.04	0.097	0.611
$HR_{70\%}$ (bpm)	160.99 ± 12.70	**-0.448**	**0.013**
$RPE_{70\%}$	10.73 ± 2.62	**-0.495**	**0.005**
$VO_{2Economy80\%}$	37.21 ± 2.91	0.265	0.157
$HR_{80\%}$ (bpm)	170.45 ± 12.55	0.286	0.125
$RPE_{80\%}$	12.73 ± 2.66	**-0.402**	**0.028**
$VO_{2Normalized70\%}$	138.51 ± 13.19	**0.415**	**0.022**
$VO_{2Normalized80\%}$	154.55 ± 14.71	**0.642**	**<0.001**

$VO_{2Economy70\%}$ (ml·kg^{-1}·min^{-1}): Oxygen consumption at RE test with 70% of VO_{2peak}, $HR_{70\%}$ (bpm): Heart rate at RE test with 70% of VO_{2peak}, $RPE_{70\%}$: Rating of perceived exertion at RE test with 70% of VO_{2peak}, $VO_{2Economy80\%}$ (ml·kg^{-1}·min^{-1}): Oxygen consumption at RE test with 80% of VO_{2peak}, $HR_{80\%}$ (bpm): Heart rate at RE test with 80% of VO_{2peak}, $RPE_{80\%}$: Rating of perceived exertion at RE test with 80% of VO_{2peak}.

The results of RE test were presented in Table 3. The S-index showed no significant correlation with the variables of $VO_{2\text{-}Economy70\%}$ (ml·kg^{-1}·min^{-1}), $VO_{2\text{-}Economy80\%}$ (ml·kg^{-1}·min^{-1}) and $HR_{80\%}$ (bpm) ($p>0.05$). However, there is a moderate to strong negative correlation between the S-index and the variables of $HR_{70\%}$ (bpm) (r= -0.448) and $RPE_{70\%}$ (r= -0.495). A moderate negative correlation was found between $RPE_{80\%}$ and S-index (r= -0.402). There is a moderate positive correlation between the S-index and $VO_{2Normalized70\%}$ (ml·kg$^{-0.66}$·min^{-1}) (r=0.415), and a strong positive correlation between the S-index and $VO_{2Normalized80\%}$ (ml·kg$^{-0.66}$·min^{-1}) (r= 0.642) ($p<0.05$).

Descriptive statistics of pulmonary function test variables and the correlation results are seen in Table 4. A strong positive correlation was observed between the S-index and the variables of FVC (L) (r= 0.634) and FEV_1 (L) (r= 0.600). A very strong positive correlation was found between the S-index and the variables of PEF (L/s) (r= 0.768) and MVV (L/min) (r= 0.770) ($p<0.05$).

Table 4. Descriptive statistics of pulmonary function test variables and correlations between the variables and dynamic IMS

Variables	Mean ± SD	S-index (cmH_2O)	
		r	p
FVC (L)	5.31 ± 1.03	**0.634**	**<0.001**
FEV_1 (L)	4.34 ± 0.73	**0.600**	**<0.001**
FEV_1/FVC (%)	83.35 ± 7.77	-0.135	0.475
PEF (L/s)	9.57 ± 1.81	**0.768**	**<0.001**
FEF 25-75% (L/s)	4.39 ± 1.35	0.148	0.435
VC (L)	6.20 ± 1.50	0.361	0.050
MVV (L/min)	176.90 ± 36.41	**0.770**	**<0.001**
FVC (L)	5.31 ± 1.03	**0.634**	**<0.001**

FVC (L): Forced vital capacity, FEV_1 (L): Forced expiratory volume in one second, FEV_1/FVC (%): FEV_1/FVC ratio, PEF (L/s): Peak expiratory flow, FEF25-75% (L/s): Forced expiratory flow between 25%–75% of vital capacity, VC (L): Vital capacity, MVV (L/min): Maximal voluntary ventilation.

Discussion

This study was conducted to investigate the relationship between dynamic inspiratory muscle strength and some selected variables related to aerobic capacity. Inspiratory muscle strength showed a positive and significant relationship with body composition variables, LBM, TBW, and BMI. Similarly, it showed a significant positive correlation with respiratory function variables, such as FVC, FEV_1, PEF, and MVV. Concerning the relationship between VO_{2peak} and RE tests, which can be considered the most important findings of this study, there is a positive and significant relationship between IMS and VO_{2peak} (ml·kg^{-1}·min^{-1}), while no significant relationship was found between IMS and VO_2 (ml·kg^{-1}·min^{-1}) results at RE tests. In addition, finding a positive relationship between IMS and the normalized VO_2 results of economy tests indicates that higher respiratory muscle strength does not mean higher RE performance.

It is known that high-intensity exercise activates the respiratory muscle metaboreflex and induces peripheral vasoconstriction; thus, blood flow to working muscles is restricted (Arslan & Melekoğlu, 2019; Babcock, Pegelow, Harms, & Dempsey, 2002; Deliceoğlu, Çakır, et al., 2024; Dempsey, Amann, Romer, & Miller, 2008; Fernández-Lázaro et al., 2021; Jurić, Labor, Plavec, & Labor, 2019). Thus, the respiratory system can be considered as a limiting element for performance. However, if the inspiratory muscles are trained or strengthened, the respiratory muscle metaboreflex triggering can be delayed and exercise performance can be enhanced (Arslan & Melekoğlu, 2019; Deliceoğlu, Çakır, et al., 2024; Fernández-Lázaro et al., 2021; Jurić et al., 2019). The finding of a significant relationship between IMS and VO_{2peak} because of our study supports this information. It appears that participants with high IMS also have high VO_{2peak} values, or vice versa. Similar to our results, Gök et al. (2024) found a moderately significant positive relationship between IMS and estimated VO_{2max} in physically active university students. While a significant relationship was found between IMS and VO_{2max} in the studies with untrained subjects (Gök et al., 2024), as in our study, no significant relationship was observed in those with trained athletes, as in the studies of Deliceoğlu, Kabak, et al. (2024) and McConnell et al. (1997). Training studies have shown that respiratory muscle performance is not the limiting factor for elite athletes (Williams, Wongsathikun, Boon, & Acevedo, 2002), but it is a limiting factor for untrained individuals (Boutellier & Piwko, 1992).

Regarding RE results, we found no significant relationship between IMS and VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$) of RE tests but a significantly positive relationship with normalized VO_2 ($ml \cdot kg^{-0.66} \cdot min^{-1}$) results. Accordingly, higher VO_2 ($ml \cdot kg^{-0.66} \cdot min^{-1}$) values at the RE test, which are associated with higher IMS, indicate a worse exercise economy. RE is complicated and a combination of varied characteristics such as metabolic, which is related to energy utilization to enable optimum performance; cardiorespiratory, which is related to decreased work outcome for transport and utilization processes of oxygen; biomechanical and neuromuscular, which are related to the interactive relation between the neural and musculoskeletal systems (Barnes & Kilding, 2015). Oxygen delivery by the cardiorespiratory system (heart, lungs, and blood) is crucial for VO_{2max}, while metabolic adaptations in skeletal muscle are crucial for enhancing submaximal performance (Bassett & Howley, 2000). It is reported that improved IMS may be effective in facilitating oxygen delivery by enhanced circulatory responses (Sasaki, Kurosawa, & Kohzuki, 2005). The primary importance of different mechanisms for VO_{2max} and RE may explain our different correlation results regarding these two variables.

IMS showed a significant negative relationship with RPE values at the RE tests. Our study showed that high inspiratory muscle strength was associated with lower fatigue perception in submaximal exercises, but this significant relationship was not found in maximal exercise. The knowledge that perceptual responses usually decrease at submaximal-intensity exercises supports our RPE results of RE tests (Barnes & Ludge, 2021). On the other hand, during near-maximal intensity exercises, dyspnea can be a critical factor, such as fatigue. Barnes and Ludge (2021) reported that performance improvement may be related to the decrease in rating of perceived dyspnea after an inspiratory muscle warm-up, but not to RPE. This result may support our nonsignificant RPE result of the maximal test (VO_{2peak}), although we did not examine the rating of perceived dyspnea. Similarly, while inspiratory muscle strength did not show a significant relationship with HR at the RE test with higher intensity, it showed a significant negative relationship with the maximum heart rate ($HR_{70\%}$) obtained from the RE test with lower intensity. It is known that RE evaluated at high-intensity is impacted more than at low-intensity (Chen et al., 2009). Between the cardiac system and respiratory muscles, especially the diaphragm, there is an interactive relationship that impacts the development of venous return and reduces resting heart rate (Ladriñán-Maestro, Sánchez-Infante, Martín-Vera, & Sánchez-Sierra, 2024; Sasaki et al., 2005). However, on the contrary, respiratory muscle fatigue may restrict exercise capacity and negatively affect the cardiovascular system (Ladriñán-Maestro et al., 2024). Diaphragm fatigue stimulates metaboreflex and induces increased heart rate (Welch, Archiza, Guenette, West, & Sheel, 2018). This fatigue also enhances the perception of effort and reduces exercise tolerance and performance (Ladriñán-Maestro et al., 2024). Therefore, inspiratory muscle fatigue may be the reason for our RPE and HR results with the maximal test in our study, which were different from submaximal tests (RE), since fatigue arises in the diaphragm as the intensity of exercise surpasses 80% of the maximum (Deliceoğlu, Çakır, et al., 2024; Dempsey et al., 2008). On the other hand, in the study of Chen et al. (2009), the authors considered 70% of VO_{2max} as below the lactate threshold, 80% of VO_{2max} as close to the lactate threshold, and 90% of VO_{2max} as above the lactate threshold based on their experiences and previous studies. In our study, we found that high respiratory muscle strength (RMS) was associated with high aerobic capacity, or vice versa, during the maximal test, which is above the lactate threshold, but higher RMS did not indicate better running economy performance during the submaximal RE test, which is most probably below or close to the lactate threshold. Our maximal exercise testing may have caused diaphragm fatigue because exercise intensity >85% of VO_{2max} leads to diaphragm fatigue, and a work rate >80% of VO_{2max} leads to improved limb O_2 transport substantially (Amann, Pegelow, Jacques, & Dempsey, 2007). These all led us to think that cardiorespiratory-based reasons may support our VO_{2peak} results, while other factors such as physiological features (muscle strength, muscle fiber type, and leg stiffness) (Li, Xu, & Xu, 2020), biomechanical variables (Tartaruga et al., 2012), numerous lower body features (Barnes, Mcguigan, & Kilding, 2014), and especially running technique (Folland, Allen, Black, Handsaker, & Forrester, 2017) may support more the RE results in our study.

Concerning body composition, we found a significant positive relationship between the variables of LBM, TBW, and BMI, and inspiratory muscle strength. Contrary to our results, Ergezen, Menek, and Demir (2023) found that body composition was not associated with respiratory muscle strength (MIP and MEP) in young, non-obese healthy individuals. Also, although the study results of Gök et al. (2024) do not support ours, as they found no significant relationship between the S-index and any body composition variables in male university students of a similar age group. However, there is also some research with similar findings to our study results. For instance, Hackett and Sabag (2021) detected a positive and significant relationship between FFM and maximal expiratory pressure (MEP) in non-athletic men, while they found a moderate positive significant relationship between fat-free mass index value (FFMI; kg/m^2) and MIP as well after the contribution of body height difference was eliminated. They also found no significant relationship between RMS and fat mass and between RMS and body fat percentage (Hackett & Sabag, 2021). In another research study conducted in healthy children and adolescents, the findings of BMI and FFM as significant predictors of RMS, including MIP and MEP, align with our study results. In the same study, there was no significant correlation between body fat (%) and RMS (Hulzebos et al., 2018).

It is known that fat-free mass is related not only to inspiratory muscle strength but also to respiratory function (Azad & Zamani, 2014). While Maiolo, Mohamed, and Carbonelli (2003) concluded that improvement in muscular mass leads to linear raises for spirometry variables in healthy individuals, Azad and Zamani (2014) detected lean body mass as a significant indicator of lung function in sedentary young women. These findings from various research support the strong relationship between IMS and pulmonary function variables found in our study. Regarding MVV as an indirect measurement of RMS in the literature (Bairapareddy et al., 2021) supports the very strong relationship found between IMS and MVV in our study.

Similar to our pulmonary function results, Gök et al. (2024) also observed a strong and positive correlation between IMS and respiratory function variables, FVC, FEV_1, VC, and MVV, in male university students at the same ages as our participants. In another study on healthy male and female young adults, a significant relationship was also found between MIP and FVC, FEV_1, and MVV (Bairapareddy et al., 2021). As for the training studies, while FVC and FEV_1 increased after an 8-week RMT in adolescent taekwondo athletes in the study of Koç and Saritas (2019), no significant alteration was found in pulmonary function variables after a 4-week RMT in competitive runners in the study of Amonette and Dupler (2002). Ozmen et al. (2017) detected no significant improvement in FVC, FEV_1, and MVV after 5 weeks of RMT in male soccer players. It is evident that results can change according to research type, age, gender, and characteristics of the sample group, sports branch, and length of training period.

Despite the importance of RE for aerobic exercise performance, there is neither an experimental study to test the effect of inspiratory muscle training on RE nor a correlation study to test the relations between IMS and RE, to the best of our knowledge. Therefore, the most notable finding of our research study is that increased dynamic inspiratory muscle strength is associated with greater oxygen consumption in the VO_{2peak} test, but higher VO_2 values in the RE test, which are associated with higher dynamic inspiratory muscle strength, do not mean better exercise economy. The fact that our results could not be evaluated according to gender due to the limited number of participants is one of the limitations of this study. The physical activity level and nutritional habits of the participants were not considered, and these are also limitations. We recommend that these limitations should be eliminated in future studies while evaluating the current or further results.

Conclusion and Recommendations

It was found that dynamic inspiratory muscle strength was positively and strongly related to lean body mass and some pulmonary function variables, FVC, FEV_1, PEF, and MVV. As for the results of VO_{2peak} and RE, which are important determinants of aerobic capacity, it can be concluded that inspiratory muscle strength was substantially related to oxygen consumption at maximal exercise (VO_{2peak} test) rather than submaximal exercises (RE tests), which was a moderate and positive relation. On the other hand, high inspiratory muscle strength was associated with lower fatigue perception at submaximal exercises but not at maximal exercise.

Because the RE is a more suitable performance estimator than VO_{2max} in runners with similar VO_{2max}, for future studies, we recommend examining whether these results found in untrained individuals in our study are also valid for elite athletes/runners or not. As we measure only inspiratory muscle strength as an indicator of respiratory muscle strength, we also recommend determining expiratory muscle strength to test the correlations with the same variables. Lactate threshold measurement should also be included in future studies since it is a critical factor for aerobic performance, such as VO_{2max} and RE.

Author's Note:

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Conflict of Interest

The authors have no conflicts of interest regarding the publication of this article.

Author Contributions

Research Idea: GA and BC; Research Design: BC, MK, DA, and TH; Data Analysis: GA and BC; Manuscript Writing: GA, BC, TH; Critical Review: BC, MK, DA, and TH.

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