Snaga inspiratorne dišne muskulature utječe na anaerobnu izdržljivost u vrhunskih sportaša

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Inspiratory muscle strength affects anaerobic endurance in professional athletes

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To the best of our knowledge, little is known about the role of respiratory muscle strength and endurance on athlete performance in anaerobic conditions of maximal exertion. The aim of this cross-sectional study was therefore to examine the association between the strength/endurance of inspiratory muscles in a group of 70 healthy male professional athletes (team sports) and their ventilatory and metabolic parameters at the anaerobic threshold (second ventilatory threshold; VT2) and beyond it at maximum load during the cardiopulmonary exercise test (CPET) on a treadmill. Ventilatory parameters at VT2, at maximal effort, and their differences were tested for association with inspiratory muscle strength (PI_{max}) and endurance (T_{lim}), measured as time to maintain inspiration at or above 80% of PI_{max}. The difference in end-tidal oxygen tension ($\Delta PETO_2$) between VT2 and maximal effort was significantly associated with resting heart rate (HR) and systolic blood pressure (BP), PI_{max}, and lean body mass (LBM) (r^2=0.26, p=0.016; multivariate regression analysis). The difference in carbon dioxide output (ΔVCO_2) was significantly associated with body mass index (BMI), resting HR, systolic BP, and PI_{max} (r^2=0.25, p=0.022; multivariate regression analysis). Our findings suggest that it is the inspiratory muscle strength and not endurance that affects the performance of professional athletes and that it should be tested and trained systematically.

KEYWORDS: anaerobic threshold; cardiopulmonary exercise testing; performance; respiratory muscle function; top athletes

Exercise capacity or physical fitness is determined by the efficiency of gas exchange during external and internal breathing to provide sufficient oxygen supply to and carbon dioxide removal from working muscles (1, 2). Evaluation of the functional response with the analysis of gases during cardiopulmonary exercise testing (CPET) is a gold standard for determining functional and pathophysiological limitations (1) in professionals working under high levels of physical stress such as scuba divers, pilots, professional soldiers, and professional athletes. During physical activity, lung ventilation [measured with maximal oxygen uptake (VO_2 max), minute ventilation-carbon dioxide (VE-VCO_2) slope, and estimated aerobic/anaerobic thresholds] increases with the load and the need of skeletal muscles for oxygen and activates auxiliary respiratory muscles besides the diaphragm (3). Respiratory muscle function is determined by the strength and endurance of respiratory muscles (4).

Many studies have shown that the inspiratory muscles fatigue after a short-term high-intensity exercise (5–7) and after a long-term moderate-intensity exercise (8). This fatigue decreases exercise endurance (9–11) and can be a limiting factor. High-intensity exercise triggers respiratory muscle metaboreflex – a heightened sympathetic nerve activity that causes peripheral vasoconstriction and limits blood flow to working muscles and therefore their energy output and consumption for the sake of breathing (12, 13). However, if the inspiratory muscle is trained, the triggering of the respiratory muscle metaboreflex can be postponed and performance increased (14).

To the best of our knowledge research conducted this far has not studied the role of respiratory muscle strength and endurance in athlete performance in anaerobic conditions of maximal exertion. Starting from the premise that it can have a significant role, the aim of this study was to determine how exactly the strength and/or endurance of the inspiratory muscles can affect the ventilatory and metabolic parameters in a group of top athletes at and beyond the anaerobic threshold during CPET on a treadmill.

PARTICIPANTS AND METHODS

Participants

The study included 70 highly trained healthy male professional handball or basketball players aged 16–36

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years. It was conducted as a part of a regular checkup of their physical fitness. Both sports are classified as having a moderate static and high dynamic component (IIC category; >70% of the estimated maximal oxygen uptake achieved) (16). Our participants were not involved in any kind of regular respiratory training. All gave their informed consent to enter the study, which followed the principles of the Declaration of Helsinki and Good Clinical Practice and was approved by the institutional review boards/ethics committees of the participating institutions.

Study design

The study used a cross-sectional association design for strength and endurance of inspiratory muscles with the CPET ventilatory and metabolic parameters determined on the checkup day together with the anthropometric measurements and blood analyses. All participants were tested for the strength of inspiratory muscles (PI_{max}), measured as the maximum pressure produced at inspiration, and for their endurance (T_{lim}), defined as the maximum time to maintain inspiration at 80% of maximum inspiratory pressure. The association between strength/ endurance of inspiratory muscles was tested for the anaerobic part of the measured CPET ventilatory and metabolic parameters, when both the stress and the stimulus for breathing are the highest. Treadmill was used for CPET because it produces higher VO_2 max and higher load than a bicycle (17).

Methodology

The regular checkup included detailed examination in the following order: history, vital signs with heart rate (HR) and blood pressure (BP) measurement at rest, resting ECG, physical examination, blood drawing and analysis, inspiratory muscle strength and endurance testing, anthropometric measurements, spirometry, and maximal effort CPET on a treadmill. Systolic and diastolic BP measurements were repeated during the second minute of recovery after CPET in an upright position. Heart rate and oxygen saturation (SaO_2) were measured in parallel at rest and during recovery using a pulse oximeter on the right hand index finger.

Anthropometric measurements included body height (BH) and body mass (BM), the circumferences of both upper and lower extremities, the circumferences of abdomen, gluteus, and chest, and 7-site skinfold thickness measurements (chest, abdominal, thigh, triceps, subscapular, suprailiac, and midaxillary) using a Harpenden skinfold calliper (Baty International Ltd, Burgess Hill, UK) for the calculation of the percentage of body fat (18). Skinfolds in all athletes were measured by a single trained and experienced technician according to the American College of Sports Medicine (ACSM) guidelines (19). Lean body mass (LBM) was calculated by subtracting body fat from BM. Body mass index (BMI) was calculated by dividing BM in kilograms with squared BH in meters.

A fasting blood sample was taken in the morning from a cubital vein in a supine position. Venous blood was analysed for red blood cell count, haemoglobin, and haematocrit.

Respiratory muscle strength and endurance were tested with a Respifit S inspiratory muscle training device (Eumedics Medizintechnik GmbH, Austria) prior to CPET testing (done after a resting period of 15 minutes). We measured maximum inspiratory strength as the maximum inspiratory mouth pressure (PI_{max})(20, 21) and inspiratory muscle endurance as the maximum time to maintain PI_{max} at or above 80% (T_{lim}) (4). The bar was raised to 80%, because previous testing in top athletes showed that 60% of PI_{max} was not discriminative in that specific population. Spirometry was measured in an upright position on a computerised spirometer Ganshorn PowerCube (Schiller, Baar, Switzerland) according to the American Thoracic Society/European Respiratory Society (ATS/ERS) standard (22) and expressed as percentage of reference values according to Quanjer et al. (23). For CPET we used the Quasar® treadmill (h/p/cosmos gmbh, Nussdorf, Germany) with the incremental load (ramp) protocol at 1.5° fixed elevation. The testing started at an initial speed of 3 km/h, with continuous acceleration rate of 1 km/h per minute and ending with exhaustion (24, 25). This protocol can also assess cardiorespiratory fitness and determine five training zones. The first three zones (recovery, extensive aerobic, intensive aerobic) are separated by speed increments lasting about ¼ of the exercise duration, and ¼ is allocated to the last two anaerobic zones. To get comparable results, we used the same protocol for all athletes. Before testing, all athletes took a 3–5 minute warmup exercise. Tidal volume (VT), end tidal oxygen ($FETO_2$), and carbon dioxide fractions ($FETCO_2$) were measured with the Ganshorn PowerCube gas flow measurement system (Schiller) at rest, during physical load, and five minutes into the recovery. The device was (re)calibrated with the reference gas mixture before each test. Testing was supervised by an educated physician and carried out at 20–22 °C, in accordance with the guidelines for exercise testing (25, 26).

Maximal oxygen consumption (VO_2 max) was defined as the peak of averaged VO_2 consumption (every 10 seconds) at the plateau (a change in VO_2 <2 mL/kg/min or <5%, regardless of further change in workload). Second ventilatory, i. e. anaerobic threshold (VT2) was identified and evaluated in each participant according to Wasserman et al. (3). Ventilatory and metabolic CPET parameters analysed at VT2 and maximal load were VO_2, carbon dioxide output (VCO_2), respiratory exchange ratio (RER), minute ventilation (VE), exercise tidal volume (VT), respiratory rate (RR), breathing reserve (BR), heart rate (HR), oxygen pulse (O_2pulse), end-tidal oxygen tension ($PETO_2$), end-tidal carbon dioxide tension ($PETCO_2$), end tidal oxygen fraction ($FETO_2$), end tidal carbon dioxide fraction ($FETCO_2$), ventilatory equivalent for oxygen (VE/VO_2), and ventilatory equivalent for carbon dioxide (VE/

VCO_2). During CPET, electrocardiogram (ECG) readings were also monitored and recorded.

Statistical analysis

The sample size (minimal number of subjects, 39) was calculated using the expected R squared for a multivariate analysis of 0.36 with up to five independent variables, using a statistical power of 90% and alpha of 0.05. Categorical data are expressed as number and percentage. Numerical data are expressed as mean and standard deviation (SD) or as median (M) and interquartile range (IQR), depending on the type of distribution. The normality of numerical data distribution was tested with the Kolmogorov-Smirnov test. Numerical data not following normal distribution were normalised using the appropriate method depending on the distribution prior to further analysis. The association of variables was assessed with univariate and multivariate regression analysis. Variables associated with outcome variables at the $P<0.1$ level were entered into the multivariate models using a backward stepwise approach. For the analysis we used Statistica, version 12 (StatSoft Inc., Tulsa, OK, USA). $P<0.05$ was considered statistically significant for all tests (a correction of p-value was done for tests where multiple comparisons were done).

RESULTS

Participant anthropometric measurements and other baseline data are given in Table 1. All variables were within reference ranges, including the lung function parameters.

PI_{max} significantly correlated with BMI (r=0.34, p=0.003), LBM (r=0.30, p=0.010), and marginally with BM (r=0.23, p=0.057). T_{lim} correlated inversely with the percentage of body fat (r=-0.24, p=0.046) and systolic and diastolic blood pressure (r=-0.31, p=0.009; r=-0.24, p=0.046; respectively) but not with other baseline values (p>0.15 for all). PI_{max} and T_{lim} did not correlate (r=0.08, p=0.537).

Table 2 shows the CPET results for VT2, maximum load, and the difference between the two. The average VO_2 max was in the expected range for handball and basketball players (56.11±6.22 mL/kg/min).

PI_{max} significantly correlated with the maximal load (r=0.28, p=0.021), VO_2 max (r=0.25, p=0.044), and marginally with VE max (r=0.22, p=0.066) and O_2pulse max (r=0.22, p=0.066) but not with other CPET parameters at maximal load (p>0.10 for all). T_{lim} did not correlate with any of the CPET parameters at maximal load (p>0.14 for all). As expected, absolute VO_2 max (L/min) significantly correlated with BM (r=0.74, p<0.001), LBM (r=0.79, p<0.001), BMI (r=0.54, p<0.001), and body fat (r=0.28,

Table 1 Anthropometric measurements and baseline respiratory data in male professional handball and basketball players (N=70)

Variables	Mean	SD	Range
Age (years)	22.0	4.6	16–36
Body height (cm)	187.2	10.5	171.5–215.0
Body mass (kg)	83.7	14.1	65.5–122.0
Body mass index (kg/m^2)	23.72	2.12	19.52–29.42
Body fat (%)	11.12	4.20	4.84–22.32
Lean body mass (kg)	77.0	12.2	58.4–103.1
Resting heart rate (per min)	75	14	51–92
Systolic blood pressure (mmHg)	123	9	104–142
Diastolic blood pressure (mmHg)	81	8	50–98
SaO_2 at rest (%)	98.1	1.1	95–100
PI_{max} (cmH_2O)	126	31	51–184
T_{lim} (sec)*	148	37-652	15–1200
FVC (% predicted)	101.74	10.46	81–123
FEV_1 (% predicted)	104.39	10.89	82–138
MEF_{25} (% predicted)	107.07	30.37	62–175
MEF_{50} (% predicted)	97.00	22.79	65–160
PEF (% predicted)	110.43	14.94	83–163
RBC count (10^{12}/L)	4.98	0.28	4.55–5.80
Hemoglobin (g/L)	152	7	134–167
Hematocrit (%)	0.437	0.020	0.386–0.481

*All data are presented as mean, SD, and range, except for T_{lim}, which is presented as median, IQR, and range. Abbreviations: SaO_2 – oxygen saturation; PI_{max} – maximum inspiratory mouth pressure; T_{lim} – maximum time to maintain inspirations; FVC – forced vital capacity; FEV_1 – forced expiratory volume in 1 second; MEF_{25} – maximal expiratory flow at 25% of FVC; MEF_{50} – maximal expiratory flow at 50% of FVC; PEF – peak expiratory flow; RBC – red blood cell; SD – standard deviation; IQR – interquartile range p=0.021). Relative VO_2 max (mL/kg/min) inversely correlated with BM (r=-0.40, p=0.001), BMI (r=-0.35, p=0.003), bodyfat(r=-0.41, p=0.001), and LBM(r=0.27, p=0.023). Neither absolute nor relative VO_2 max correlated with PI_{max} or T_{lim} in the multivariate regression analysis.

At VT2 (anaerobic threshold), PI_{max} significantly correlated with the load (r=0.34, p=0.005), VO_2 (r=0.27, p=0.026), VCO_2 (r=0.27, p=0.028), VE (r=0.25,p=0.044), O_2pulse(r=0.25, p=0.041), and marginally with VT (r=0.22, p=0.068) but not with other CPET parameters (p>0.300 for all). T_{lim} did not correlate with any of the CPET parameters (p>0.130 for all). In the multivariate regression analysis neither absolute nor relative VO_2 at VT2 correlated with PI_{max} or T_{lim} (p>0.05 for all).

Considering the shift from VT2 to maximal load, PI_{max} significantly correlated with the change in VCO_2 (r=-0.27, p=0.025), RER (r=-0.25, p=0.037), and $PETO_2$ (r=-0.25, p=0.043) but not with the change in other CPET parameters (p>0.100 for all). T_{lim} did not correlate with any of the changes in CPET parameters between VT2 and maximum load (p>0.370 for all).

Multivariate analysis showed that the change in $PETO_2$ significantly correlated with the resting HR, systolic BP, PI_{max} and marginally with LBM (R^2=0.26, p=0.016; Table 3). The change in VCO_2 significantly correlated with BMI, resting HR, systolic BP, and PI_{max} (R^2=0.25, p=0.022; Table 4). The same pattern of association was found for the change in RER.

DISCUSSION

Relative inefficiency of ventilation can be related to an inappropriate strength and endurance of respiratory muscles, causing seemingly mild but important reduction in exercise tolerance in top athletes. This study revealed respiratory muscle weakness in a significant proportion of participants, even though their resting lung function parameters were all within the reference ranges. To the best of our knowledge, this is also the first study to show significant independent association between PI_{max} and the change in $PETO_2$, VCO_2, and RER between VT2 and the maximal effort, which confirms that inspiratory muscle strength is associated with the efficacy of breathing and gas exchange at maximal effort (above the anaerobic threshold).

Table 2 Cardiopulmonary exercise test results for second ventilator threshold, maximum load, and the difference for all subjects (N=70)

Variables	VT2		Maximal load		Difference between maximal load and VT2	
	Mean±S		Mean±SD		Mean±SD	
Test duration (min)	12.0	1.7	14.6	1.5	2.6	1.0
Load (W)	356	58	419	69	58	58
VO_2 (L/min)	4.14	0.66	4.68	0.73	0.54	0.21
VO_2 (mL/kg/min)	49.52	5.99	56.11	6.22	6.48	2.44
VO_2 (mL/kg$_{LBM}$/min)	53.85	5.94	61.07	6.22	7.09	2.86
VCO_2 (L/min)	4.38	0.69	5.61	0.89	1.15	0.80
VCO_2 (mL/kg/min)	52.47	6.98	67.36	8.52	13.75	9.37
VCO_2 (mL/kg$_{LBM}$/min)	57.09	6.75	73.15	8.72	15.92	5.75
RER	1.06	0.05	1.20	0.06	0.13	0.15
VE (L/min)	114.16	18.80	148.75	21.94	34.74	14.98
VT (L)	2.64	0.51	2.78	0.48	0.15	0.29
Respiratory rate (per min)	44.24	8.15	54.11	7.69	9.89	6.53
Breathing reserve (%)	34.79	9.29	14.87	10.72	-19.87	8.38
Heart rate (per min)	179.28	8.54	191.18	7.35	11.99	5.52
O_2pulse	23.11	3.73	24.35	3.85	1.23	1.03
$PETO_2$	101.02	4.75	105.86	4.23	3.33	11.64
$PETCO_2$	40.61	3.59	40.79	3.63	0.19	6.60
$FETO_2$	14.66	0.69	15.36	0.62	0.49	1.70
$FETCO_2$	5.88	0.52	5.90	0.50	0.02	0.98
VE/VO_2	27.75	3.31	31.96	3.28	4.23	2.56
VE/VCO_2	26.18	2.64	26.64	2.39	0.39	1.59

Abbreviations: VT2 – second ventilatory threshold; VO_2 – oxygen consumption; LBM – lean body mass; VCO_2 – carbon dioxide output; RER– respiratory exchange ratio; VE– minute ventilation; VT– exercise tidal volume; O_2pulse– oxygen pulse; $PETO_2$–end-tidal oxygen tension; $PETCO_2$ – end-tidal carbon dioxide tension; $FETO_2$ – end tidal oxygen fraction; $FETCO_2$ – end tidal carbon dioxide fraction; VE/VO_2 – ventilatory equivalent for oxygen; VE/VCO_2 – ventilatory equivalent for carbon dioxide

Table 3 Results of the multivariate regression analysis for the difference in $PETO_2$ between maximal effort and VT2 (dependent variable); R^2=0.26, p=0.016 for the model

	β	SE (of β)	b	SE (of b)	T	p-value
Intercept			33.856	32.225	1.051	0.300
LBM	0.268	0.151	0.309	0.175	1.769	0.085
Resting heart rate	0.358	0.146	0.371	0.151	2.455	0.019
Systolic blood pressure	-0.301	0.147	-0.502	0.245	-2.047	0.047
PI_{max}	-0.418	0.152	-0.177	0.064	-2.755	0.009

Abbreviations: $PETO_2$ – end-tidal oxygen tension; VT2 – second ventilatory threshold; LBM – lean body mass; PI_{max} – inspiratory muscle strength; SE – standard error

Table 4 Results of the multivariate regression analysis for the difference in VCO_2 between maximal effort and VT2 (dependent variable); R^2=0.25, p=0.022 for the model

	β	SE (of β)	b	SE (of b)	T	p-value
Intercept			0.914	2.341	0.391	0.698
BMI	0.439	0.160	0.170	0.062	2.738	0.009
Resting heart rate	0.344	0.155	0.024	0.011	2.226	0.032
Systolic blood pressure	-0.310	0.153	-0.035	0.017	-2.028	0.049
PI_{max}	-0.408	0.153	-0.012	0.004	-2.668	0.011

Abbreviations: VCO_2 – carbon dioxide output; VT2 – second ventilatory threshold; BMI – body mass index; PI_{max} – inspiratory muscle strength; SE – standard error

Contrary to our results, Klusiewicz (27) did not find a correlation between PI_{max} and absolute or relative values of VO_2 max in male athletes but did find a correlation between PI_{max} and relative VO_2 max in female athletes. He proposed that further endurance training in well-trained individuals such as his male athletes would not increase inspiratory muscle strength. The discrepancy in the results between our and Klusiewicz's study could be explained by lower PI_{max} in our male athletes, which suggests that they did not reach their maximum inspiratory muscle strength potential.

Aerobic performance seems to be affected by body composition and body mass, especially by lean body mass (28, 29). Our study supports these findings by demonstrating that BM, BMI, and LBM were positively associated with the absolute VO_2 max values. Greater respiratory muscle strength was associated with higher total muscle mass (significant association between PI_{max} and LBM). Multivariate analysis has showed that these two factors act as independent predictors for the efficacy of ventilation in the anaerobic part of workout. Hulens et al. (30) showed that persons with a higher percentage of body fat had noticeably lower VO_2 max relative to their body mass. In line with these data, the percentage of body fat in our study inversely correlated with CPET endurance parameters (VO_2 max, VO_2 max/BM or maximal speed reached on a treadmill) but also with inspiratory muscle endurance (T_{lim}). As VO_2 can be limited by many factors (3) and as it reached the plateau (VO_2 max) before maximal load in all our athletes, it was not surprising that VO_2 at VT2 and VO_2 max and the difference between the two did not significantly correlate with PI_{max} and T_{lim} in the multivariate analysis.

Respiratory limitation to exercise performance in healthy young subjects has already been reported by earlier studies. One showed respiratory muscle fatigue during high intensity exercise, and a correlation between the severity of fatigue and baseline inspiratory muscle strength (6). Another study showed greater resistance to respiratory muscle fatigue in athletes than non-athletes (31), which suggests that whole body training improves inspiratory muscle strength and fatigue resistance. Martin and Chen (2) have proposed that resistance to respiratory muscle fatigue is a product of physical training and not of a genetic predisposition. Our study, in contrast, showed significant variability of inspiratory muscle strength and consequently CPET results and anaerobic endurance in a group of young, healthy, and highly trained professional athletes, which implies that the level of athletic fitness is not the sole predictor of respiratory muscle strength and fatigue resistance. Instead, it is more likely that the endurance of respiratory muscles should depend on the training of respiratory muscles in athletes competing in endurance sports (low static and high dynamic load) (32).

Respiratory muscle fatigue can limit exercise performance by activation of respiratory muscle metaboreflex (13). Ultimately, increased alveolar ventilation is not the only mechanism to augment the transport and the use of oxygen to meet increased demands during exertion. This is also supported by our findings that the change of $PETO_2$ and VCO_2 between VT2 and maximal effort significantly correlated with inspiratory muscle strength and parameters indirectly representing the sympathetic status (resting HR and systolic BP). The respiratory muscle metaboreflex can be particularly limiting for performance in healthy subjects during very intense endurance exercise (33). In professional athletes with higher respiratory muscle strength this reflex is attenuated, and they can achieve better results.

On the other hand, excessive metabolic production of CO_2 can only be excreted by increased ventilation. If respiratory muscle strength or endurance fall short of the increased ventilation demand, tissue and blood CO_2 will increaseand cause metabolic acidosisand thus the failure of both skeletal and respiratory musculature. This is supported by our findings that the change in VCO_2 and RER between VT2 and maximal effort correlated inversely with PI_{max}.

Although the correlations between CPET parameters and PI_{max} in our athletes were weak (accounting for 25–26% of variability), they nevertheless confirm the importance of inspiratory muscle strength in such a competitive population, especiallyinlightofthecomplexexternaland internal breathing process that includes many factors and several steps (3).

The limitations of our study come from the relatively short duration of CPET (14.6 minutes and 2.6 minutes after the second ventilatory threshold) together with high inspiratory muscle endurance in our group of athletes. Thus T_{lim} canbeofverylimiteddiscriminativepowerandresults for the inspiratory muscle endurance have to be interpreted with caution. Additional bias could come from the association between PI_{max} and LBM established by univariate analysis, as it limits and complicates the interpretation of the obtained results, but despite this association, these two factors were shown to be independent predictors of the efficacy of ventilation (multivariate analysis). Ourfindingsabouttheenduranceofinspiratory musclescallforfurthertestingwithlongerduration CPET protocol (slower increment) that would include not only this group of athletes but also general population or recreational athletes as controls.

Practical application

Our findings support the role of respiratory muscle strength and not as much the endurance of inspiratory muscles in physical performance at professional level in sports and other professions with moderate level of static and high level of dynamic load. They also suggest that targeted training could improve and preserve that strength, as opposed to regular training. Endurance training of the inspiratory muscles with resistance masks does not seem to makeadifferenceforprofessionalswithmoderatelevel of static and high level of dynamic load.

Conflicts of interest

None to declare. Theauthorsalonearereponsiblefor the content and writing of the manuscript.

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Snaga inspiratorne dišne muskulature utječe na anaerobnu izdržljivost u vrhunskih sportaša

Cilj ovog presječnog istraživanja, u kojem je sudjelovalo 70 zdravih muškaraca vrhunskih sportaša (momčadskih sportova) bio je ispitati povezanost snage/izdržljivosti inspiratorne muskulature i ventilacijskih i metaboličkih parametara na anaerobnom pragu (drugi ventilacijski prag; VT2) te nakon njega pri maksimalnom opterećenju tijekom kardiopulmonalnog testiranja na tekućoj traci (CPET). Ventilacijski parametri na VT2, pri maksimalnom naporu te njihova razlika testirani su na povezanost sa snagom inspiratorne muskulature (PI_{max}) i izdržljivošću (T_{lim}), koja je izmjerena kao vrijeme tijekom kojega se zadržava ventilacija na ili iznad 80% PI_{max}. Razlika tlaka kisika na kraju izdaha između VT2 i maksimalnog napora ($\Delta PETO_2$) značajno je bila povezana sa srčanom frekvencijom (HR) i sistoličkim krvnim tlakom (SBP) u mirovanju, s PI_{max} i bezmasnom masom tijela (LBM) (r^2= 0,26, p=0,016; multivarijatna regresijska analiza). Razlika izdahnutog CO_2 (ΔVCO_2) značajno je bila povezana s indeksom tjelesne mase (BMI), HR-om i SBP-om u mirovanju te s PI_{max} (r^2=0,25, p=0,022; multivarijatna regresijska analiza). Rezultati ovog istraživanja upućuju na to da snaga, a ne izdržljivost inspiratorne muskulature značajno utječe na radni učinak (izvedbu) vrhunskih sportaša te da ju je potrebno sustavno mjeriti i trenirati.

KLJUČNE RIJEČI: anaerobni prag; funkcija dišne muskulature; kardiopulmonarno testiranje u naporu; radni učinak; vrhunski sportaši