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Respiratory adaptations in different types of sport

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Abstract. – OBJECTIVE: Recent studies demonstrated that current European Respiratory Society/American Thoracic Society spirometric reference equations, used in general population, may not be applicable in population of elite athletes. Althought it is well known that physical activity may affect lung volumes, the effect of sporting activity on pulmonary function testing indices was never examined. The aim of this study was to examine the differences in functional respiratory parameters in various types of sports by measuring lung volumes and to extend the existing factors as well as sport disciplines which affect respiratory function the most.

SUBJECTS AND METHODS: A total of 1639 elite male athletes, aged 18-35 years were divided in 4 groups according to the predominant characteristics of training: skill, power, mixed and endurance athletes. They performed basic anthropometric measurements and spirometry. Groups were compared, and Pearson's simple correlation was performed to test the relation between anthropometric and spirometric characteristics of athletes.

RESULTS: All anthropometric characteristics significantly differed among groups and correlate with respiratory parameters. The highest correlation was found for body height and weight.

CONCLUSIONS: Sports participation is associated with respiratory adaptation, and the extent of adaptation depends on type of activity. Endurance sports athletes have higher lung volumes in comparison with skill, mixed and power group of sport.

Key Words:
Lung volumes, Top athlete, Exercise.

Introduction

It is well known that the musculo-skeletal and the cardiovascular system are actively involved during muscular exercise and that both organ systems undergo adaptive changes in response to regular endurance exercise. In contrast, it is generally believed that respiratory system is not significantly different in physically trained individuals when compared with sedentary population[1]. Considering the fact that all of them are involved in oxygen transportation, the exact reason for the substantially lesser extent of pulmonary system adaptation prolonged exercise are not completely understood. However, it was never examined the effect of sporting activity on pulmonary function testing indices that is FEV_1 and FVC and the FEV_1/FVC ratio[2].

In general population, predicted values of lung volumes are based on age, gender, race, and height. The ERS/ATS reports on lung volume measurements and its reference value for children and adults are widely used, even for athletic population[3,4]. However, there are no normative predictive values for athletes, and reference values for general population overestimate lung function in athletes[5].

Lung development, and consequently lung volumes, could change its performance depending on type, intensity, severity, duration and frequency of sports activity[6].

The purpose of this investigation was to examine the differences in functional respiratory parameters in various types of sports, by measuring lung volumes. The second aim was to find out which sport disciplines improves respiratory function the most.

Subjects and Methods

Subjects

A cross-sectional study was conducted during a 2-yr period from November 2012 to February

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2014 in Serbian Institute of Sports in Belgrade. The study included 1639 male athletes. The Institutional Review Board for Medical Ethics approved the research protocol.

Inclusion criteria were: male athletes (who are at least five years of active, competitive play sports and train at least 15 hours a week), ages between 18 and 35 years and who participated in international competition.

Exclusion criteria were: respiratory symptoms (current infection, any kind of chest discomfort, history of serious pulmonary disease and thoracic injury including rib fractures), physical findings suggesting cardiopulmonary disease, evident chest deformity, steroid abuse, injuries which seeked to rest for at least 3 months in last year. Subjects were included in the study if they did not meet any of the exclusion criteria.

The mean age of all participants was 22±4 years (range 18-35). We classified the athletes into 4 subgroups according to the predominant characteristics of training: 1) skill (primary tehnical activity [n=115] i.e., artistic gymnastic, fencing, karate, taekvondo, golf, table tennis, equestrian and sailing; 2) power activities (primarily isometric activities [n= 69] featuring weightlifting, wrestling, short- distance running (100-200 m); 3) mixed disciplines (combining isometric and isotonic components [n=1225], including soccer, basketball, handball, volleyball, water polo, tennis); 4) endurance disciplines (primary isotonic activities [n=230] including rowing and canoeing, swimming, long-distance running and marathon, cycling, triathlon and pentathlon[7].

Methods

Testing was started between 09:30 and 11 AM by filling out a standardized sports medical questionnaire which contains 36 questions (concerning personal, family and the history of systems). The questionnaire was supplemented with information about when the subject started to work out, how many times daily and weekly is he training, what type of training, as well as the duration of each workout. At the end of the questionnaire subjects put its signature confirming the accuracy of the data. Completed, and then reviewed the questionnaire was used for the definitive selection of the subjects reported.

The testing took place in laboratory settings, at the same time of day (morning), the same instruments and technique. Measurements were carried out under standard environmental conditions; comfort temperature (between 18-22°C), the atmospheric pressure of 760 mmHg, and a relative atmospheric humidity of 30 to 60%. The temperature, humidity and atmospheric pressure were continuously measured at the lab.

Spirometry was performed using the (Turninac, Pneumotah) Pony FX (Cosmed Pulmonary Function Equipment, Rome, Italy). Spirometry was performed following the ATS/ERS recommendations[3]. Body mass (kg; Seca 761 scales, ± 0.5 kg; Seca Co., Hamburg Germany) and stature (m; Cranlea JP60 portable stadiometer, + 0.001 m; Cranlea & Co) were also measured using standardized anthropometric techniques. Body mass index (BMI) was calculated for all the participants as the ratio of body mass (kilograms) divided by body height (meters) squared. The participant's percentage of body fat (BF %) was measured using the bioimpedance segmental body composition analyzer (BC-418 Segmental Body Composition Analyzer, Tanita, IL, USA).

Statistical Analysis

Continuous data are expressed as mean ± SD. Categorical data are expressed as frequencies. Statistical significance was set for a 2-tailed *p* value <0.05. One-way analysis of variance with multiple Bonferroni post hoc tests was used to assess differences between athletes according to the types of sports in which they participated. Data are adjusted for age and height. Pearson's simple correlation was performed to test the relation between anthropometric and spirometric characteristics of athletes. Statistical analysis was performed using SPSS software version 12.0 (SPSS, Inc., Chicago, IL, USA).

Results

Demographic characteristics of athletes are listed in Table I. There was no difference in age among groups. In all other anthropometric parameters they statistically significantly differed. The highest athlete, as well as toughest, belonged to mixed group. BMI for skills, power, mixed group had statistically significant relevance according to endurance group. Skill group statistically significant differed in percentage of body fat and muscle.

Spirometric values for each group are showed in Tables II and III. There was statistical significant relevance in VC for power and mixed group to endurance group.

Table I. Demographic characteristics in athletes according to type of sport.

Variable	Skill (n = 115)	Power (n = 69)	Mixed (n = 1225)	Endurance (n = 230)	p
Age (years)	23.77 ± 4.78	25.14 ± 4.24	21.38 ± 4.12	22.37 ± 4.25	NS
Body height (cm)	181.04 ± 7.42$^{\varnothing}$	180.22 ± 7.89$^{\varnothing}$	190.61 ± 10.21$^{\#}$	183.48 ± 8.64	<0.001
Body weight (kg)	78.75 ± 12.93$^{\varnothing}$	81.47 ± 17.93$^{\#}$	87.26 ± 14.18	77.36 ±11.57	<0.001
BMI (kg/m^2)	23.99 ± 3.31$^{\#}$	25.14 ± 4.83$^{\varnothing\#}$	23.91 ± 2.69$^{\#}$	23.05 ± 2.48	<0.001
BF (%)	13.92 ± 6.06$^{*\varnothing\#}$	10.53 ± 2.97	10.79 ± 3.13	10.31 ± 3.01	<0.001
BM (%)	49.83 ± 3.76$^{*\varnothing\#}$	52.59 ± 2.04	52.45 ± 2.55	52.74 ± 2.29	<0.001

Data are expressed as mean±SD. One-way analysis of variance showed no differences for age between groups ($p > 0.05$). BMI-body mass index; BF-body fat, BM-body muscle, NS- not significant. $^{*}p < 0.05$ vs power athletes; $^{\varnothing}p < 0.05$ vs mixed athletes; $^{\#}p < 0.05$ vs endurance athletes

Table II. Spirometric characteristics in athletes according to type of sport- respiratory parameters expressed in litres.

Variable	Skill (n = 115)	Power (n = 69)	Mixed (n = 1225)	Endurance (n = 230)	p
VC (L)	6.1 ± 0.8	5.8 ± 0.6$^{\#}$	6.0 ± 1.1$^{\#}$	6.2 ± 0.9	<0.001
FVC (L)	5.8 ± 0.8	5.7 ± 1.03$^{\#}$	5.8 ± 0.04$^{\#}$	6.0 ± 0.9	0.003
FEV1 (L)	5.1 ± 0.6*	5.0 ± 0.6*	5.0 ± 1.1$^{\#}$	5.1 ± 0.7	NS
FEV1/VC	83.1 ± 7.1	84.6 ± 5.9$^{\#}$	83.4 ± 8.0$^{\#}$	81.2 ± 6.6	<0.001
PEF (L)	10.9 ± 1.7	10.4 ± 1.7	10.8 ± 2.25	10.9 ± 2.1	NS
FEV1/VC	83.1 ± 7.1	84.6 ± 5.9$^{\#}$	83.4 ± 8.0$^{\#}$	81.2 ± 6.6	<0.001
MVV (L)	183.6 ± 36.3$^{\varnothing}$	165.2 ± 44.0$^{\#}$	175.9 ± 38.6	180.7 ± 41.2	0.004

Data are expressed as mean ± SD. FVC-forced vital capacity; FEV1-forced expiratory volume in1 second; PEF-peak expiratoy flow; VC-vital capacity; FEV1/VC-Tiffeneau-Pinelli index; MVV-maximum voluntary ventilation. $^{\varnothing}p < 0.05$ vs mixed athletes; $^{\#}p < 0.05$ vs endurance athletes.

Group correlation presents analysis for all 4 investigated groups together (skills, power, mixed, endurance, respectively). All anthropometric parameters correlate with respiratory parameters. The highest correlation was found for body height and weight in skill, mixed and especially in endurance group. Body height had positive influence on VC, FVC and FEV_1 in power activities, while body weight influenced only on FEV_1. Also, all anthropometric parameters had negative correlations with FEV_1/FVC, statistically not significant only in cases of BF and BM.

Discussion

Lung volumes were significantly higher than reference values in all groups of athletes. Our results support the fact that most of the athletes adhered to a high volume of respiratory system similar to those reported before[8,9].

The higher respiratory parameters were found in endurance group. Apart height, which is standardized for spirometric reference value, we also observed significant relationship between body weight and lung function parameters in athletes. There are several potential reasons why athletes have higher lung volumes. Exercise training improves endurance and strength of respiratory muscles; it also causes resistance reduction in respiratory canals, and increases lung elasticity and alveolar expansion. Therefore, selection of appropriate type of exercise training may be an important factor in prevention or lowering of respiratory diseases and increase the efficacy of this system. On the other hand, there are some data that respiratory muscle training (RMT) and particularly inspiratory muscle training (IMT) are the ways how an athlete could improve his/her performance[10,11]. The impact of RMT on sport performance is quite contentious. Some studies demonstrated minimal influence on performance, whereas other reports describe improved sport performance after RMT.

In our study, the higher percentage of VC, FVC and FEV_1 had endurance group of athletes (rowing

Table III. Spirometric characteristics in athletes according to type of sport presented as the percentage of predictive values for age and height.

Variable	Skill (n = 115)	Power (n = 69)	Mixed (n = 1225)	Endurance (n = 230)	p
VC (%)	104.4 ± 12.3	101.4 ± 11.1#	102.5 ± 13.0#	106.7 ± 11.5	<0.001
FVC (%)	104.7 ±12.1	102.5 ± 11.2	103.4 ± 14.2#	107.2 ± 11.9	0.001
FEV1 (%)	106.9 ± 11.4	104.8 ± 9.5	105.2 ± 13.8	107.7 ± 10.9	NS
FEV1/VC (%)	100.3 ± 9.0	101.5 ± 8.0#	100.5 ± 9.3#	98.1 ± 7.8	0.002
PEF (%)	110.3 ± 17.9	107.7 ± 15.8	109.6 ± 20.4	108.9 ± 19.5	NS
MVV (%)	115.2 ± 24.9	110.2 ± 18.6	111.6 ± 28.4#	115.5 ± 26.3	NS

Data are expressed as mean ± SD. FVC-forced vital capacity; FEV1-forced expiratory volume in1 second; PEF-peak expiratoy flow; VC-vital capacity; FEV1/VC-Tiffeneau-Pinelli index; MVV-maximum voluntary ventilation. $^{\#}p < 0.05$ vs endurance athletes.

and canoeing, swimming, long-distance running and marathon, cycling, triathlon and pentathlon) and the lowest value for FVC/ FEV_1. Above mentioned parameters was significantly lower in mixed sport group, while power group had lower only VC. Previous studies had shown that endurance athletes had greater FVC, FEV_1 and FEV_1 values, but lower FEV_1/FVC than the sedentary population[12]. Endurance athletes have a higher and prolonged demand for gas exchange, and thus ventilation during exercise, than power athletes and non-athletes. This is reflected by the observation that endurance athletes might develop hypoxaemia[5]. Similar to Degens, taking everything into account, with the exception of FEV_1/FVC (the quotient, dependent on age) we concluded that lung volumes are better in endurance athletes than non-athletes[12]. In case of rowing and canoeing there are possible explanations for the benefit of RMT because of its related physiological and mechanical demands. During rowing, the accessory and primary inspiratory muscles are not only recruited for ventilation but also contribute significantly to stabilization of the thorax for more efficient transmission of force during the pulling movement of the oars. Thus, the dual demands placed on the respiratory muscles may lead to breathing becoming entrained to the pattern of movement to maintain performance[13]. Some meta-analyses of sports performance showed that swimmers and divers showed no overall improvement in measures of respiratory muscle strength and endurance, but higher lung volumes might be explained with the fact that water pressure on their thorax during regular swimming training already induces RMT[14].

In endurance exercise (long-distance running and marathon, cycling, triathlon and pentathlon) the pulmonary system is usually not considered to be a limitation to performance. In addition, longitudinal studies of subjects involved in land based activities showed lung volume to be unaffected by short term training. Our results disagree with previous studies that have measured lung volumes in these sports[15]. Looking into correlations analysis for endurance group, all investigated parameters (excluding BF which had negative correlation) had high significant correlation with investigated

Table IV. General correlations for all groups of sport.

	VC (l)	FVC (l)	FEV^1 (l)	FEV1/VC	PEF (l)	MVV (l)
Age (years)	0.111**	0.099**	-0.021	-0.211**	0.241**	0.138**
Body height (cm)	0.663**	0.552**	0.428**	-0.205**	0.377**	0.356**
Body weight (kg)	0.594**	0.197**	0.119**	-0.243**	0.323**	0.332**
BMI (kg/m²)	0.212**	-0.143**	-0.128**	-0.154**	0.100**	0.132**
BF (%)	-0.123**	0.138**	0.146**	-0.016	-0.085**	-0.053*
BM (%)	0.127**	-0.041**	0.058**	-0.008	0.039	0.052

BMI-body mass index; BF-body fat, BM-body muscle; FVC-forced vital capacity; FEV1-forced expiratory volume in 1 second; PEF-peak expiratoy flow; VC-vital capacity; FEV1/VC-Tiffeneau-Pinelli index; MVV-maximum voluntary ventilation.
*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

respiratory parameters. Those findings are similar to some other previous researches[16,17]. On the other hand Hagberg et al[16] reported that values for static lung volumes (TV and FVC) of accomplished marathoners and other endurance trained athletes were no different from those of untrained controls of comparable body size. However, Cordain et al[17] reported larger than normal static lung volumes in swimmers and divers when compared to normal non-athletes[17]. Also, compared to the other sports included in this study (except swimming) more force has to be generated while running at great speed in the erect posture which is the normal body position in humans[18]. Comparative studies between endurance and other sport have not been done yet.

In general population, pulmonary function varies with age, standing height, sex and ethnicity[4]. As it was expected, in our study, there were significant differences in body composition parameters among groups.

We found the highest statistically correlations between body height and body weight with VC, FVC, FEV_1, PEF and MVV (but not for FEV_1/FVC). As in general population, body height had the greatest influence on all respiratory parameters in our subjects. Percentage of BF had statistically significant correlation with FVC, FEV_1 but negative correlation with VC, PEF, MVV. In fact, the latter, had only negative correlations with BF, among all anthropometric parameters. With the exception of power athletes BF was inversely related to all respiratory parameters.

Percentage of body muscles had positive correlation with VC, FEV_1 and negative with FVC, and FEV_1/FVC. In fact, BM was the only parameter which had no correlation with PEF and MVV. In endurance and mixed activity group, body mass had statistically high correlations with all respiratory parameters, while in skill and power activities there was no correlations.

Our results strongly suggest that the intensity or severity of the sports engaged in by the athletes probably determines the extent of strengthening of the respiratory muscles with a resultant increase in the lung volumes. Elite athletes have significantly higher lung volumes compared to currently predicted values of non-athletes. Apart improvement of lung function in endurance athletes, there are some disagreement about risk of sudden death in this particular group of sport and influence of type and intensity of training on heart remodeling[19]. This potential discrepancy could emphasise further investigations combining lung and heart function together not just for endurance sport, but for the others sports as well. Individuals participating in sporting activities may have higher spirometric values compared to predict ones for general population which may lead to misclassification of this population and misdiagnosis during evaluation from clinicians.

Our work suggest necessity for spirometric reference value for athletes and possible consideration of including body weight in calculating and predict reference value, apart general known parameters.

Conclusions

Our study included only male athletes' ages 18-35 years old.

Sports participation is associated with respiratory adaptation, and the extent of the adaptation depends of type of activity. Athletes who participate in endurance sports activities (rowing and canoeing, swimming, long-distance running and marathon, cycling, triathlon and pentathlon) have higher lung volumes in comparison with skill, mixed and power group of sport. All investigated parameters of body composition influence on respiratory parameters.

Study perspectives: The study was conducted on a large sample size of athletes who perform wide range of different type of sport. The fact that inspiratory muscle fatigue occurs during sport activity provides further challenge to investigate the potential role of respiratory muscles training as a method to enhance physical performance. Clear patterns of the sport that shows the most obtains or the most efficacious training protocol of inspiratory/respiratory muscle training are more difficult to perceive. Rowing and canoeing, swimming, long-distance running and marathon, cycling, triathlon and pentathlon are the sports which improve respiratory system the most.

Conflict of Interest

The Authors declare that they have no conflict of interests.

References

1) Twisk JW, Staal BJ, Brinkman MN, Kemper HC, van Mechelen W. Tracking of lung function parameters

and the longitudinal relationship with lifestyle. Eur Respir J 1998; 12: 627-634.

2) Myrianthefs P, Grammatopoulou I, Katsoulas T, Baltopoulos G. Spirometry may underestimate airway obstruction in professional Greek athletes. Clin Respir J 2014; 8: 240-247.

3) Miller MR, Hankinson J, Brusasco V, Burgos F, Casaburi R, Coates A, Crapo R, Enright P, van der Grinten CP, Gustafsson P, Jensen R, Johnson DC, MacIntyre N, McKay R, Navajas D, Pedersen OF, Pellegrino R, Viegi G, Wanger J; ATS/ERS Task Force. Standardization of spirometry. Eur Respir J 2005; 26: 319-338.

4) Quanjer PH, Stanojevic S, Cole TJ, Baur X, Hall GL, Culver BH, Enright PL, Hankinson JL, Ip MSM, Zheng J, Stocks J; ERS Global Lung Function Initiative. Multi-ethnic reference values for spirometry for the 3-95-yr age range: the global lung function 2012 equations. Eur Respir J 2012; 40: 1324-1343.

5) Dempsey JA, McKenzie DC, Haverkamp HC, Eldridge MW. Update in the understanding of respiratory limitations to exercise performance in fit, active adults. Chest 2008; 134: 613-622.

6) Meylan CM, Cronin JB, Oliver JL, Hopkins WG, Contreras B. The effect of maturation on adaptations to strength training and detraining in 11-15-year-olds. Scand J Med Sci Sports 2014; 24: 156-156.

7) Caselli S, Autore C, Serdoz A, Santini D, Musumeci MB, Pelliccia A, Agati L. Three-dimensional echocardiographic characterization of patients with left ventricular non compaction. J Am Soc Echocardiogr 2012; 25: 203-209.

8) Ireland A, Korhonen M, Heinonen A, Suominen H, Baur C, Stevens S, Degens H, Rittweger J. Side-to-side differences in bone strength in master jumpers and sprinters. J Musculoskelet Neuronal Interact 2011; 11: 298-305.

9) Korhonen MT, Cristea A, Alen M, Hakkinen K, Sipila S, Mero A, Viitasalo JT, Larsson L, Suominen H. Ageing, muscle fiber type, and contractile function in sprint- trained athletes. J Appl Physiol 2006; 101: 906-917.

10) Legrand R, Marles A, Prieur F, Lazzari S, Blondel N, Mucci, P. Related trends in locomotor and respiratory muscle oxygenation during exercise. Med Sci Sports Exerc 2007; 39: 91-100.

11) McMahon ME, Boutellier U, Smith RM, Spengler CM. Hyperpnea training attenuates peripheral chemosensitivity and improves cycling endurance. J Exp Biol 2002; 205: 3937-3943.

12) Degens H, Rittweger J, Parviainen T, Timonen KL, Suominen H, Heinonen A, Korhonen MT. Diffusion capacity of the lung in young and old endurance athletes. Int J Sports Med 2013; 34: 1051-1057.

13) Volianitis S, McConnell AK, Koutedakis Y, McNaughton L, Backx K, Jones DA. Inspiratory muscle training improves rowing performance. Med Sci Sports Exerc 2001; 33: 803-809.

14) Kilding AE, Brown, S, McConnell AK. Inspiratory muscle training improves 100 and 200 m swimming performance. Eur J Appl Physiol 2010; 108: 505-511.

15) Doherty M, Lygeri Dimitriou L. Comparison of lung volume in Greek swimmers, land based athletes, and sedentary controls using allometric scaling. Br J Sports Med 1997; 31: 337-341.

16) Hagberg JM, Yerg JE 2nd, Seals DR. Pulmonary function in young and older athletes and untrained men. J Appl Physiol 1988; 65: 101-105.

17) Cordain L, Tucker A, Moon D, Stager JM. Lung volumes and maximal respiratory pressures in collegiate swimmers and runners. Res Q Exerc Sport 1990; 61: 70-74.

18) Stocks J, Quanjer PH. Reference values for residual volume, functional residual capacity and total lung capacity. Eur Respir J 1995; 8: 492-506.

19) Leischik R, Dworrak B. Ugly duckling or Nosferatu? Cardiac injury in endurance sport – screening recommendations. Eur Rev Med Pharmacol Sci 2014; 18: 3274-3290.