Word Count: Abstract 199/250, Text – 2077/2600

Tables: 3

Title: Static and dynamic lung volumes in swimmers and their ventilatory response to maximal exercise

(Short title: Ventilatory response in exercised swimmers)

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Conflict of Interest: No conflicts exist for any of the authors
Funding Information: No funding
Prior Presentation/Publication: None

Acknowledgements: The authors would like to thank the participants for giving their time freely.

Abstract

Purpose: While the static and dynamic lung volumes of active swimmers is often greater than the predicted volume of similarly active non-swimmers, little is known if their ventilatory response to exercise is also different.

Methods: Three groups of anthropometrically matched male adults were recruited, daily active swimmers (n = 15), daily active in fields sport (Rugby and Football) (n = 15), and recreationally active (n = 15). Forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), and maximal voluntary ventilation (MVV) was measured before and after exercise to volitional exhaustion.

Results: Swimmers had significantly larger FVC (6.2 ± 0.6 L, 109 ± 9 % pred) than the other groups (5.6 ± 0.5 L, 106 ± 13 % pred, 5.5 ± 0.8, 99 % pred, the sportsmen and recreational groups respectively). FEV_1 and MVV were not different. While at peak exercise, all groups reached their ventilatory reserve (around 20%), the swimmers had a greater minute ventilation rate than the recreational group (146 ± 19 vs 120 ± 87L/min), delivering this volume by breathing deeper and slower.

Conclusions: The swimmers utilised their larger static volumes (FVC) differently during exercise by meeting their ventilation volume through long and deep breaths.

Keywords: Tidal volume, swimmers, $\dot{V}O_2$ max, ventilatory reserve, MVV

Introduction

The ventilatory response to exertion is well known, with ventilation ($\dot{V}_E$) increasing progressively with intensity, where the response is achieved through increases in both tidal volume (V_T) and breathing rate. [1-3] During progressive aerobic exercise, the initial increase in $\dot{V}_E$ is achieved first through an increase predominantly in V_T, and later via a marked increase in breathing rate as V_T approaches a plateau at approximately 50-60% of the lungs vital capacity. [1, 4-6]

The respiratory system has not been fully considered as a limiting factor in maximal exercise performance because of the existence of a significant breathing reserve as ventilation never reaches the maximum available (MVV). [7-9] In healthy recreationally active adults 56-69% of $\dot{V}_E$, is used. [3]. Little research has focused on swimmers, who synchronise their breathing with their strokes.

Competitive swimmers have static and dynamic lung volumes that are significantly greater than age and stature matched non-swimmers. [10-12] However it is unclear as to whether these differences in lung function are due to a genetic predisposition, or an effect of training. [11,13]

The study investigates whether the ventilatory response to exercise in swimmers is different to other athletes. The aim is to compare maximal exercise using cycle ergometry in swimmers and two groups of matched non-swimmers. A further aim is to compare the static and dynamic lung volumes between the three groups

Materials and Methods

Subjects. Three groups of healthy adult males (n=45) were recruited, group one were daily active swimmers (n =15), group two daily active field sports men (Rugby and Football) (n = 15) and a recreationally active group who exercised irregularly (n = 15) (**Table 1**). The study was ethically approved by the School Ethics committee, and all participants provided written consent. All participants were asked to avoid strenuous and prolonged physical activity in the 24 hours preceding their test session since forced vital capacities (FVC) have been shown to be temporarily reduced following acute exercise, whilst residual volumes are temporarily increased. [14,15].

Test Procedures: A fixed cycle ergometer (Lode Corival, Groningen, The Netherlands) was used to exercise the participants. Oxygen consumption ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$), pulmonary ventilation, breathing parameters and lung function were assessed using a calibrated metabolic gas analyser (Oxycon pro, Jaeger, Germany). Heart rate was recorded using an ECG secured to the chest (Polar, Polar Electro, Finland)

Whilst wearing a nose clip and seated, the FVC, forced expiratory volume in 1 second (FEV_1), and peak expiratory flow (PEF) were recorded. Following this, three 12s long maximum voluntary ventilation manoeuvres were performed. For this manoeuvre, participants were vigorously encouraged to breathe as deeply and as rapidly as possible for the full 12s, the highest value recorded being used for analysis.

After five-minutes of sitting quietly on the ergometer, resting breathing parameters were recorded for three minutes. The participants then performed an incremental cycle test to volitional exhaustion at a self-selected cadence. The initial workload for the first minute for all participants was 50 W, thereafter increasing incrementally at a rate determined by a prediction equation using the height, age, and weight of each individual participant. [16] The exercise test was halted when the participant reached volitional fatigue, or could no longer maintain their self-selected cadence. Respiratory parameters were recorded continuously during while heart rate was recorded at each minute following the initiation of the incremental exercise. After exercising the participants rested for thirty minutes before the lung volume measurements were repeated. The exercise intensity was determined to be maximal only when the respiratory exchange ratio was greater than 1.15, and at least 90% of an age predicted heart rate maximum was achieved. [17]

Data Analysis. All data are presented as the mean ± SD unless stated otherwise. For the spirometric data, the largest values for FVC and FEV_1 before and after exercise were used. The MVV values used for analysis for each participant were selected in similar fashion. Differences between pre-and post-exercise values for each exercise groups spirometric data were assessed using a paired samples t-test. Differences between the three groups for all variables were determined using a one-way MANOVA. A value of $p < 0.05$ being considered significant. All statistical analyses were performed using statistical software (SPSS version 20, IBM, Chicago, USA).

Results

Spirometry revealed that the swimmers had the greatest static volumes, with FVC both before and after the maximal exercise test, being larger than both non-swimming groups (recreational, $p < 0.01$, field sports, $p = 0.02$) (**Table 2**). With the dynamic volumes, overall no differences were found for FEV_1 or MVV between any of the groups. However, within the filed sports group the FVC, $FEV_{1,}$ and MVV did increase slightly ($p < 0.05$) (**Table 2**).

The field sports group and swimming groups exercise peaked at similar ($p > 0.050$) workloads (300 ± 68 and 305 ± 43 W respectively) and $\dot{V}O_2$ (52 ± 10 and 53 ± 7 ml/min/kg respectively) (**Table 3**). As expected, the recreational group produced significantly lower peak values (**Table 3**). The peak $\dot{V}_E$ achieved by the swimming and field sports groups (146 ± 19 vs 141 ± 28 L/min, respectively) was significantly greater than the recreational group ($p < 0.05$) at 120 ± 87 L/min (**Table 3**). An important observation is the swimming group achieved this at a lower breathing rate at 48 ± 5 breathes/min (**Table 3**). This is reflected in similar changes in V_T with the swimmers possessing the greatest maximum volumes at 3.1 ± 0.4 L (**Table 3**).

The peak $\dot{V}_E$ and V_T volumes achieved during maximal exercise were compared to the initial static and dynamic lung volumes (**Table 3**). At peak exercise, all three groups used the same portion of their MVV (87 ± 21, 83 ± 18, 76 ± 24 %, swimmers, field sports and recreational groups respectively), leaving a ventilatory reserve of around 18%. Similarly, all three groups used the same portion of their FVC (50 ± 8, 47 ± 10, 43 ± 12 % swimmers, field sports and recreational groups respectively) (**Table 3**).

Discussion

This study compares groups of swimmers and non-swimmers, matched anthropometrically and in terms of exercise performance. However, the swimmers differ by adopting an alternative breathing strategy to gain their $\dot{V}_{E\,peak}$. At their peak exercise level opting to breathe slower and more deeply than the non-swimmers.

Higher volumes for FVC (around 10 % above their predicted value) were found for swimmers in comparison to both the field sportsmen and the recreational groups (**Table 2**) reflecting the findings of others. [10-11,13, 18-19]

This study found no difference in FEV_1, or MVV, which contrasts with some other studies, which have shown higher values in swimmers and lower values in sedentary or recreationally active people. [10-11, 20-21] A study by Lazovic *et al.*, [13] assessed whether specific sport training had any bearing on respiratory function. Comparing fifteen different sports and a physically inactive group, they found that athletes who competed in sports where height positively correlated with success, such as water polo and rowing, had greater lung volumes than a sedentary group. However, amongst sports such as rugby, handball, and tennis, there were no differences for values of FEV_1, MVV, or even FVC in relation to participation level. However, given that this study did not appropriately control for height between groups, and that it is well understood total lung volume is most positively correlated with height, greater volumes are expected in the taller athletes such as those competing in water polo and rowing. [22] Regardless, the authors found that some sport groups with no difference in height had equal static and dynamic lung volumes (handball, football) and even some lower lung volumes (boxing) compared to sedentary controls. Therefore, the authors suggested that besides height, other factors could have impact upon lung function such as fat free mass, thoracic diameter, and trunk length. [13,23]

The present study shows that at maximal exercise, the swimmers and field sports group reached similar $\dot{V}O_{2\,peak}$, $\dot{V}_{E\,peak}$, and workloads, all of which were significantly greater than the recreational group (**Table 3**). Despite these differences it was found that their ventilatory reserve ($\dot{V}_{E\,peak}$ expressed as a percent of MVV) were the same at around 20%. [3, 24-25]

In reaching the observed peak ventilation values, each group were shown to use the same proportion of their measured FVC (~50%). The percentage of the FVC and MVV that each group used is comparable to those observed in previous studies. [3, 24-26] Beginning with the same resting breathing rates, the intermittent group had equal tidal volumes and breathing rate at maximal exercise as the recreational group, reflected in a similar $\dot{V}_{E\ peak}$ with the recreational group consuming around 14 ml/kg/min less oxygen at $VO_{2\ peak}$. This would indicate that ventilation reaches a maximum first (obtainable by all healthy adults) and that oxygen transport and use dictates exercise capacity as a second barrier. Although the swimmers possessed a greater FVC their ventilatory reserve dictated their $\dot{V}_{E\ peak}$. However, although possessing a similar resting breathing rate as the non-swimmers, the swimmers displayed a greater $V_{T\ Peak}$ at 3.1 ± 0.4 L as opposed to 2.3 - 2.6 L for the non-swimmers (the field sports and recreation groups). The 80% ventilatory reserve dictated that the swimmers respiratory cycle increased and was 12% slower than the non-swimmers (**Table 3**). If the swimmers had a matching respiratory rate of around 55 breaths/min their $\dot{V}_{E\ peak}$ would equal 171 L/min, using a further 10% of their ventilatory reserve. Where the swimmers tachypnoeic switch occurs needs further investigation especially as it may aid in improving swimming performance.

Whether the different lung volumes and capacities reported in swimmers is due to their training, the result of a genetic predisposition, or a mixture of both, has been investigated in other studies. [11,13, 20, 27] In support of the importance of genotype, it has been reported that swimmers tend to be taller than age and weight matched peers, and that these anthropometric characteristics are influenced by genetic inheritance. [11]. Rather than the influence of height alone, further support in favour of a genetic contribution exists through other studies reporting greater lung volumes in talented young swimmers with limited training. [28,29] Further to this, Baxter-Jones and Helms conducted a study on 231 highly trained swimmers, gymnasts, footballers, and tennis players, whilst controlling for age, height, weight, and training status. [21] They observed that across five different age grades, swimmers had the greatest lung volumes and that the differences in lung volumes between sports did not change over time.

In support of phenotypical influence, other studies have suggested that swim training directly effects the muscle function of the respiratory system, resulting in increases in both static and dynamic lung volumes. [27, 30-32] Precisely what aspect of swim-training it is that could result in these observed increases is somewhat unclear, however, several suggestions considering the uniqueness of swimming as an exercise have been proposed, such as an altered ventilation distribution due to the altered influence of gravity when swimming in the horizontal position. [33]. Swimming in water, which is denser than air, increases the inspiratory muscle work, which may result in improved pulmonary function. [34,35] However, the absolute contributions of both swim training, and genetic endowment to the greater lung volumes observed in successful swimmers will remain unclear until further longitudinal studies examining selection, respiratory muscle strength, and training induced adaptations in greater detail are conducted. [11].

Lung volume and capacity have been reported to change after activities that require large power outputs, and sometimes lead to problems such as coughing and wheezing. [36-38] It has been observed that immediately after high intensity exercise, FVC decreases whilst residual volumes are elevated. [15,37] The data from the present study indicate that amongst swimmers and recreationally active controls, a maximal exercise test does alter static or dynamic lung function. However, the data show that the intermittent land-based athletes improve after 30 minutes of rest. Albeit, the differences are small, but represent some post-exercise relaxation in airway tone.

In conclusion, the swimmers had a larger FVC than their anthropometrically matched non-swimming groups. This larger lung volume proved significant at maximal exercise, as the swimmers could take deeper and lengthier breaths compared to the others. Although the reason for this difference is yet to be elucidated, swimmers often entrain their breathing with their stroke rate, this could perhaps require a more flexible way to reach $\dot{V}_{E\,peak}$. Further to this observation, it appears that following a maximal exercise test, respiratory function is improved in the field sports men.

References

[1] Aliverti, A. (2016). The respiratory muscles during exercise. *Breathe*, 12(2), pp.165-168.

[2] Kenney, W., Wilmore, J., Costill, D. and Wilmore, J. (2008). *Physiology Sport and Exercise*. 4th ed. Champaign, USA.

[3] Neder, J., Dal Corso, S., Malaguti, C., Reis, S., De Fuccio, M., Schmidt, H., Fuld, J. and Nery, L. (2003). The pattern and timing of breathing during incremental exercise: a normative study. *Eur Resp J*, 21(3), pp.530-538.

[4] Hey, E., Lloyd, B., Cunningham, D., Jukes, M. and Bolton, D. (1966). Effects of various respiratory stimuli on the depth and frequency of breathing in man. *Resp Physiol*, 1(2), pp.193-205.

[5] Scheuermann, B. and Kowalchuk, J. (1999). Breathing patterns during slow and fast ramp exercise in man. *Experi Physiolo*, 84(1), pp.109-120.

[6] Younes, M. and Kivinen, G. (1984). Respiratory mechanics and breathing pattern during and following maximal exercise. *J Appl Physiol*, 57, pp.1773-1782.

[7] Boutellier, U. and Piwko, P. (1992). The respiratory system as an exercise limiting factor in normal sedentary subjects. *Eur J Appl Physiol Occup Physiol*, 64(2), pp.145-152.

[8] Bye, P., Farkas, G. and Roussos, C. (1983). Respiratory Factors Limiting Exercise. *Ann Re Physiol*, 45(1), pp.439-451.

[9] Habedank, D., Reindl, I., Vietzke, G., Bauer, U., Sperfeld, A., Glaser, S., Wernecke, K. and Kleber, F. (1998). Ventilatory efficiency and exercise tolerance in 101 healthy volunteers. *Eur J Appl Physiol*, 77(5), pp.421-426.

[10] Astrand, P., Engstrom, L., Eriksson, B., Karlberg, P., Nylander, I., Saltin, B. and Thoren, C. (1963). Girl Swimmers. With Special Reference to Respiratory and Circulatory Adaptation and Gynaecological and Psychiatric Aspects. *Acta Paed.*, 52(6), pp.602-603.

[11] Doherty, M. and Dimitriou, L. (1997). Comparison of lung volume in Greek swimmers, land based athletes, and sedentary controls using allometric scaling. *Br J Sports Med*, 31(4), pp.337-341

[12] Jakovljevic, D. and McConnell, A. (2009). Influence of different breathing frequencies on the severity of inspiratory muscle fatigue induced by high intensity front crawl swimming. *Strength Conditioning Res*, 4(23), pp.1169-1174.

[13] Lazovic-Popovic, B., Zlatkovic-Svenda, M., Durmic, T., Djelic, M., Djordjevic Saranovic, S. and Zugic, V. (2016). Superior lung capacity in swimmers: Some questions, more answers. *Revista Portuguesa de Pneumologia (English Edition)*, 22(3), pp.151-156.

[14] Farrell, P., Maron, M., Hamilton, L., Maksud, M. and Foster, C. (1983). Time course of lung volume changes during prolonged treadmill exercise. *Med Sci Sports Ex*, 15(4), pp.319 - 324.

[15] Quindry, J., Brown, D., McCaw, S. and Thomas, D. (2002). Effect of Exercise-Induced Changes in Residual Lung Volume on the Determination of Body Composition. *J Strength Conditioning Res*, 16(4), p.591.

[16] Wasserman, K., Hansen, J., Sue, D., Whipp, B. and Casaburi, R. (2004). Principles of Exercise Testing and Interpretation. 4th edn. Philidelphia: Lippincott Williams and Wilkins.

[17] Howley, E., Bassett, D. and Welch, H. (1995). Criteria for maximal oxygen uptake. *Med Sci Sports Exercise*, 27(9), pp.1292-1301.

[18] Cordain, L., Tucker, A., Moon, D. and Stager, J. (1990). Lung volumes and maximal respiratory pressures in collegiate swimmers and runners. *Res Q Exerc Sport*, 61, pp.70-74.
[19] Cordain, L. and Stager, J. (1998). Pulmonary structure and function in swimmers. *Sports Med*, 6, pp.271-278.
[20] Baxter-Jones, A., Helms, P. (1993). Growth of lung function in male athletes during puberty and adolescence. *Eur Resp. J*, 6, pp.222-225.
[21] Khosravi, M., Tayebi, S., and Safari, H. (2013) Single and concurrent effects of endurance and resistance training on pulmonary function. *Iranian J Basic Med Sci*, 16, pp. 628-634
[22] Laszlo, G. (2006). Standardisation of lung function testing: helpful guidance from the ATS/ERS Task Force. *Thorax*, 61(9), pp.744-746.
[23] Cotes, J., Chinn, D. and Reed, J. (2001). Body mass, fat percentage, and fat-free mass as reference variables for lung function: effects on terms for age and sex. *Thorax*, 56, pp.839-844.
[24] Kift, J and EM Williams (2007). The respiratory time and flow profile at volitional exercise termination. J Sports Sci, 25, pp. 1599-1606.
[25] Kift J and EM Williams (2008). Ventilatory capacity and its utilisation during exercise. Lung 186: pp. 345-350.
[26] Lucia, A., Carvajal, A., Calderon, F. J., Alfonso, A., and Chicharro, J. L. (1999). Breathing pattern in highly competitive cyclists during incremental exercise. *Eur J Appl Physiol Occu Physiol*, 79, pp.512–521.
[27] Clanton, T., Dixon, G., Drake, J. and Gadek, J. (1987). Effects of swim training on lung volumes and inspiratory muscle conditioning. *J Appl Physiol*, 62(1), pp.39-46.
[28] Eriksson, B., Engstrom, I., Karlberg, P., Lundin, A., Saltin, B. and Thoren, C. (1978) Long term effect of previous swimming training in girls: a 10-year follow-up of the "Girl Swimmers". *Acta Paediatr Scand*, 67, pp285-92.
[29] Gibbons, J., Cunningham, D., Shaw, D. and Fynon, R. (1972) The effect of swimming training on selected aspects of pulmonary function of young girls: a preliminary report. In: Taylor AW, ed. *Training: scientific basis and application.* Springfield, NJ: Thomas.
[30] Lemaître, F., Clua, E., Andréani, B., Castres, I. and Chollet, D. (2009). Ventilatory function in breath-hold divers: effect of glossopharyngeal insufflation. *Eur J Appl Physiol*, 108(4), pp.741-747.
[31] Robinson, E. and Kjeldqard, J. (1982). Improvement in ventilatory muscle function with running. *J Appl Physiol*, 52, pp.1400-1405.
[32] Stavrou, V., Toubekis, A. and Karetsi, E. (2015). Changes in Respiratory Parameters and Fin-Swimming Performance Following a 16-Week Training Period with Intermittent Breath Holding. *J Hum Kinetics*, 49, pp.89-98.
[33] Shepard, R. (1972) Exercise and the lungs. In: Alexander JF, Serfass RC, Tipton CM, eds, *Fitness and Exercise.* Chicago: Athletic institute, pp.7-18.
[34] Corteix, D., Obert, P., Lecoq, A., Guenon, P. and Kock, G. (1997). Effect of intensive swimming training on lung volumes, airway resistance and on the maximal expiratory flow-volume relationship in prepubertal girls. *Eur J Appl Physiol Occu Physiol*, 76(3), pp.364-269.
[35] Newmann, F., Smalley, B. and Thomson, M. (1961). A comparison between body size and lung function of swimmers and normal school children. *J ApplPhysiol*, 156, pp.9-10.

[36] Miles, D., Cox, M., Bomze, J. and Gotshall, R. (1991). Acute recovery profile of lung volumes and function after running 5 miles. *J Sports Med Physical Fitness*, 31, pp.243-248.
[37] Rasmussen, B., Elkjaer, P. and Juhl, B. (1988). Impaired pulmonary and cardiac function after maximal exercise. *J Sports Sci*, 6(3), pp.219-228.
[38] Radovanovic, D., Bratic, M., Nurkic, M. and Stankovic, N. (2011). Recovery of dynamic lung function in elite judoists after short-term high intensity exercise. *Sci Martial Arts*, 7(1), pp.21-26.
[39] Global Lung Function Initiative. https://www.ers-education.org/guidelines/global-lung-function-initiative/spirometry-tools/desktop-individual-calculator.aspx [online] Ers-education.org. [Accessed 18 Aug. 2018].

Tables

Table 1 Population characteristics at rest.

Activity Group

Parameter	Recreational	Field Sports	Swimmers
Age (yrs)	23 ± 2 [c]	23 ± 3 [c]	21 ± 1 [ab]
Height (cm)	178 ± 8	175 ± 6	181 ± 7
Weight (kg)	81 ± 8	77 ± 11	75 ± 6
Systolic blood pressure (mmHg)	122 ± 4 [c]	119 ± 4	118 ± 3 [b]
Diastolic blood pressure (mmHg)	79 ± 5 [c]	78 ± 3 [c]	74 ± 3 [ab]
Training time (days/wk)	2 ± 2 [bc]	5 ± 1 [a]	5 ± 0 [b]
Resting $\dot{V}_E$ (L/min)	12.2 ± 1.5	14.0 ± 3.8	12.6 ± 2.3
Resting $\dot{V}O_2$ (ml/kg/min)	6.0 ± 1.5	6.6 ± 1.4	6.3 ± 1.0
Rested breathing rate, (L/min)	16 ± 2	17 ± 4	16 ± 3

Data are mean ± SD for all variables. [abc] indicates significant difference between rec[a]. field [b]. and swim[c] groups respectively.

Table 2 Respiratory data before and after maximal exercise test

	Activity Group								
	Recreational			Field Sports			Swimmers		
Parameter	Before	After	*P*	Before	After	*P*	Before	After	*P*
FVC (L)	5.49 ± 0.78 [c]	5.57 ± 0.75 [c]	0.11	5.57 ± 0.53 [c]	5.69 ± 0.53 [c]	**0.02***	6.22 ± 0.60 [ab]	6.27 ± 0.57 [ab]	0.47
FVC % pred[#]	99 ± 13	100 ± 12		106 ± 13	108 ± 10		109 ± 9	110 ± 9	
FEV_1 (L)	4.59 ± 0.62	4.57 ± 0.54	0.79	4.68 ± 0.50	4.81 ± 0.51	**0.01***	4.95 ± 0.42	4.95 ± 0.50	0.99
FEV1 % pred[#]	98 ± 12	98 ± 12		105 ± 13	108 ± 13		104 ± 11	104 ± 13	
FVC / FEV1 (%)	84 ± 4	83 ± 7	0.46	84 ± 5	85 ± 7	0.23	81 ± 7	79 ± 7	0.33
FVC / FEV1 % pred	100 ± 5	99 ± 8		99 ± 6	100 ± 8		97 ± 9	94 ± 9	
MVV (L/min)	164 ± 26	162 ± 31	0.54	173 ± 33	180 ± 31	**0.04***	170 ± 24	169 ± 26	0.78
MVV % pred	102 ± 16	101± 15		97 ± 18	93 ± 11		103 ± 13	104 ± 12	

*Data are presented as mean ± SD. [abc] represents statistically significant differences for variables between rec[a]. field. and swim[c] groups respectively. * represents statistically significant difference between pre, and post exercise test values within groups. FVC = Forced Vital Capacity, FEV_1 = Forced Expiratory volume in 1s, MVV = Maximum Voluntary Ventilation. [#]Predicted lung volumes were calculated with the use of the Quanjer GLI-2012 regression equations. [39]*

Table 3 Peak exercise data for each test group

	Activity Group		
Parameter	Recreational[a]	Field Sports[b]	Swimmers[c]
Work load max (W)	217 ± 25[bc]	300 ± 68[a]	305 ± 43[a]
HR max (bpm)	183 ± 8	184 ± 8	183 ± 9
$\dot{V}O_2$ peak (ml/kg/min)	36.1 ± 7.2[bc]	51.5 ± 10.4 [a]	52.7 ± 7.5 [a]
$\dot{V}_{E\ peak}$ (L/min)	120 ± 87 [c]	141 ± 28	146 ± 19 [a]
Peak breathing rate (L/min)	54 ± 12[c]	55 ± 11[c]	48 ± 5[ab]
$V_{T\ peak}$ (L)	2.3 ± 0.6 [c]	2.6 ± 0.6 [c]	3.1 ± 0.4 [ab]
$\dot{V}_{E\ peak}$ % of MVV	76 ± 24	83 ± 18	87 ± 21
breath / W	4 ± 1 [bc]	6 ± 1 [a]	6 ± 1 [a]
$V_{T\ peak}$ % of FVC	43 ± 12	47 ± 10	50 ± 8

Data are presented as mean ± SD for each variable. [abc] represents statistically significant differences for variables between rec[a]. field[b]. and swim[c] groups respectively.