

An innovative approach to functional spiroergometric examination among power athletes

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Abstract

This article aims to expand knowledge of and establish new diagnostic procedures. The purpose of this study was to assess ventilation and circulation parameters during exercise testing by power athletes on Ergoline Ergoselect 200P and AirBike Renegade Pro exercise bikes. The participants consisted of five elite athletes with an average age of 20.8 years. The application of the selected methodological procedures was planned over one week. The parameters included in the analysis were body composition, vital capacity, and circulation parameters of minimum and maximum blood pressure and heart rate. The ventilation parameters measured during the exercise testing included breathing rate, tidal volume, oxygen uptake, and CO₂ production. The ventilation parameters were used to determine maximal oxygen uptake (VO_{2max}) per kilogram body weight (ml.kg⁻¹.min⁻¹). The respiratory exchange ratio was expressed as the ratio of the metabolic production of carbon dioxide and the uptake of oxygen. When determining training indicators, aerobic and anaerobic zones were interpreted. The descriptive statistics, supplemented by the Spearman's rank-order correlation, were computed. The collected data were processed using nonparametric statistical methods. The differences between two groups were determined at the $p < .05$ level of significance. The results showed that the time interval required for the test was a determining factor in its practical administration. When performing all-out exercise tests on two different types of ergometers, the mean duration of the cycle ergometer test was 10 min 44 s. The AirBike test duration was shorter by 6 min 32s. Despite a significantly shorter time interval, median VO_{2max} values were higher by 3 ml.kg⁻¹.min⁻¹.

KeyWords: Ice hockey, Combat sports, Performance, Testing, Cardiovascular system, Respiratory system.

Introduction

Spiroergometry refers to functional examination and stress testing to obtain important information about an athlete's overall physical performance. In the laboratory environment, cycle ergometers and treadmills are used to conduct tests for sport diagnostics, which help us to monitor circulatory, ventilatory, and metabolic markers. In addition to these ergometers, special ergometers (simulators) are used in practice, in which case the load is simulated so as to approximate as closely as possible the actual sporting activity (Marček et al., 2007). The methodology of spiroergometric examination is based on the analysis of inhaled and exhaled air composition and serves to determine the functional response of the organism to the load (Corrà et al., 2018). There are different methodologies for performing spiroergometry exercise tests, and many exercise laboratories use their own standardized protocols (Takken et al., 2017).

The vital capacity of the lungs, which can be either inspiratory or expiratory, provides basic spirometric parameters. Low values may be a determinant for endurance sports, but since lung capacity is not primarily determined by the athlete's training but by the genetic predisposition, it cannot be considered an indicator for performance. Its value is primarily determined by body height, age, and gender. When categorizing ergometric load tests, it is necessary to consider physical units (e.g., force = mass × acceleration, work = force × trajectory, power = work × time). Performance indicates what strength and endurance capabilities an athlete has. In terms of comprehensiveness, it can be stated that spiroergometry is the most comprehensively developed methodology for investigating the oxygen transport system.

This is a method for determining cardiorespiratory fitness by analyzing exhaled air at maximal physical load. In this method, maximal oxygen consumption (VO_{2max}) is the most important indicator (Vilikus et al., 2004). Maximal oxygen consumption describes the body's ability to transport the maximum amount of oxygen to the working muscles at maximum load. In practice, VO_{2max} is interpreted as the amount of oxygen taken per minute (VO₂ [l.min⁻¹]) or, more often, in relation to body mass (ml.kg⁻¹.min⁻¹). It is determined during gradual load tests up to the maximum. In the study by Yoon et al. (2007) the recommended duration for a graded exercise test to assess VO_{2max} is 8–12 min. However, there is little consensus on an appropriate graded exercise test protocol. The use of a verification exhaustive bout was recently recommended to confirm VO_{2max}. However, it is unknown if a verification exhaustive bout performed after a longer duration graded exercise test provides a

valid estimate for $\text{VO}_{2\text{max}}$ (Jamnick et al., 2018). Performance in a spiroergometry exercise test on a cycle ergometer is primarily measured by the attained $\text{VO}_{2\text{peak}}$ and achieved peak work rate (Takken et al., 2017). Anaerobic threshold is another important indicator for an athlete's aerobic capacity, along with maximal oxygen consumption. It is a quantitative expression of utilizing the highest possible proportion of maximal oxygen consumption during extended load.

The anaerobic threshold is the highest intensity of dynamic muscle work at which lactic acid accumulates in the peripheral circulation and with which the organism is able to cope over a longer period of time. Load intensity at the anaerobic threshold ranges from 60% to 90% of $\text{VO}_{2\text{max}}$, depending on the degree of the athlete's adaptation to endurance loading. In contrast, the aerobic threshold is defined as the load intensity when anaerobic energy coverage is being transitioned to around 50%–70% of $\text{VO}_{2\text{max}}$ (Pastucha et al., 2011). Physiological variables such as maximum work rate and maximal oxygen uptake ($\text{VO}_{2\text{max}}$), together with other submaximal metabolic inflection points (e.g., the lactate threshold, the onset of blood lactate accumulation, and the pulmonary ventilation threshold), are regularly quantified by sports scientists during an incremental exercise test to exhaustion.

These variables have been shown to correlate with endurance performance, been used to prescribe exercise training loads, and are useful for monitoring adaptation to training (Bentley et al., 2007). According to Iñigo and Brooks (2018), increased muscle mitochondrial mass is characteristic of elite professional endurance athletes, whereas increased blood lactate levels at the same absolute submaximal exercise intensities and decreased mitochondrial oxidative capacity are characteristics of individuals with low aerobic power. For performance development, it is necessary to select the parameters that can be used in the training process. In terms of laboratory conditions, it is important to implement an innovative approach with emphasis on the use of specific ergometers to optimize performance during test execution. Such an approach is required in sports specializations in which performance at test realization is significantly dependent on material and technical equipment. As Várnay et al. (2020) emphasized, if a spiroergometric examination is performed on a specific source of load for a given sport, it will provide objectification and optimization of the training process.

The purpose of this study is to assess ventilation and circulation parameters during exercise testing by power athletes on Ergoline Ergoselect 200P and AirBike Renegade Pro exercise bikes. The main intention is to expand knowledge of and to establish new diagnostic procedures.

Material & methods

Participants

The research sample consisted of five male power sports athletes with an average age of 20.8 years at the time of testing. In terms of performance level, the athletes belonged to an elite group competing at both international and national levels. On average, they had active sports careers of 10 years. The characteristics of the sample are presented in Table 1.

Table 1. Description of the groups

Sport	n	BW (kg)	BH (cm)	SMM (kg)	BF (kg)	BM (kcal)
		Median $\pm$ QR (min/max)				
Ice hockey	3	98.6 $\pm$ 23.2 (78.4/101.6)	189 $\pm$ 15 (177/192)	53 $\pm$ 16.6 (38.9/55.5)	7.5 $\pm$ 4.9 (5.7/10.6)	2338.8 $\pm$ 606.9 (1833.7/2440.6)
Combat sports	2	85.6 $\pm$ 8.8 (81.2/90)	184 $\pm$ 2 (183/185)	46.5 $\pm$ 6 (43.5/49.5)	5.3 $\pm$ 0.7 (5/5.7)	2113.3 $\pm$ 226 (2000.3/2226.3)

Note. BW: body weight; BH: body height; SMM: skeletal muscle mass; BF: body fat; BM: basal metabolism; QR: quartile range.

Test protocol

Application of the chosen methodological standards was planned over one week from 21 to 23 July 2021. To ensure full recovery of energetic resources, the players and coaches were asked to reduce their training intensity 24 hours before the tests. As a first step, measurement of body composition was conducted by an InBody 720 device. Subsequently, an Ergoline Ergoselect 200P cycle ergometer and a Cortex Metalyzer 3B respiratory gas analyzer were used to measure indicators of vital capacity and circulatory parameters of minimal and maximal values of blood pressure (BP min., BP max.) and heart rate (HR min., HR max.) during the test with the application of a ramp protocol. The ventilation parameters measured during the exercise testing included breathing rate, tidal volume, oxygen uptake, and CO_2 production. The ventilation parameters were used to determine maximal oxygen uptake ($\text{VO}_{2\text{max}}$) per kilogram body weight ($\text{ml.kg}^{-1}.\text{min}^{-1}$). The respiratory exchange ratio (RER) was expressed as the ratio of the metabolic production of carbon dioxide and the uptake of oxygen. When determining training indicators, aerobic and anaerobic zones were interpreted. After 48 hours, we performed a repeated measurement on the AirBike Renegade Pro using the same methodological procedures. The AirBike is a combination of a cycle and an elliptic ergometer that enables global muscle work. The trainer mechanically uses the principle of air resistance regulated by a fan. In increasing the frequency of rotations (RPM) from baseline of 55 RPM, 3 RPM were added every 20 seconds up to the maximum. Air resistance

considered as load was expressed in watts. The AirBike Renegade Pro is decelerated by shovels of a 4.8 kg dual steel fan, which is located in the front part of the ergometer. During the test, the athletes alternatively pushed and pulled the ergometer's handgrips in addition to pedaling. The resistance was set at level two, which decelerated the air flow through the width of the shovels. The saddle height was individually set for each athlete, as was the distance from the dynamic handgrips. The angle of the knee joint in sitting position was more than 170 degrees, with the pedal at the lowest point. The foot was in a parallel position against the floor with the knee slightly about the pedals. On the AirBike Renegade Pro, the athletes held the handgrips with palms down. A doctor with the required specialization and a nurse were present for both test days, and they conducted spiroergometric examinations.

Data collection and analysis / statistical analysis

The descriptive statistics, supplemented by Spearman's rank-order correlation, were computed. The collected data were processed using nonparametric statistical methods. Mann-Whitney U test was used to identify the differences between the indicators of heart rate frequency, performance, and VO_{2max} and the time intervals during the load between the two ergometers' usage. The differences between the two groups were determined at the $p < .05$ level of significance.

The presented procedures were in accordance with the ethical standards on human experimentation and in compliance with the Helsinki Declaration. Each participant voluntarily provided written informed consent before participating (Harriss & Atkinson, 2011).

Results

The results of the pilot study indicated the potential of the fully calibrated AirBike Renegade Pro ergometer in combination with established methodology. Nevertheless, it is necessary to state that these results provided the basis for a more comprehensive analysis of more numerous samples. Gradual load examination provided a few parameters that could be used to evaluate motor fitness, trainability, and periodization of the training process. Figure 1 provides a graphic illustration of the descriptive statistics for the selected variables.

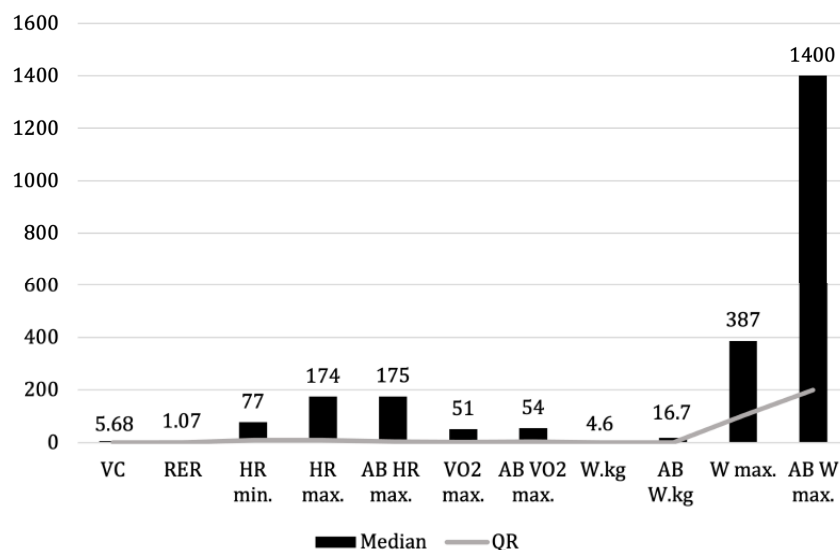


Figure 1: Median and quartile range of spiroergometric parameters

An analysis of heart rate frequency, performance in watts, and VO_{2max} showed no statistically significant difference ($p > 0.05$) between the cycle ergometer and the AirBike. On the median, the athletes achieved better VO_{2max} by $3 \text{ ml.kg}^{-1}.\text{min}^{-1}$ on the AirBike than the cycle ergometer. The main criterion was considered to be the achievement of a so-called plateau in oxygen consumption values whereby, in spite of a continued growing load, the oxygen consumption remained unchanged. The RER value reached 1.05, which indicated primary consumption of carbohydrates and confirmed the achievement of maximal effort during the test above the level of the anaerobic threshold. Resistance created by the AirBike dual steel fan was contingent on the athlete increasing revolution frequency over the time. This was also linked to the performance, which was 12.1 W.kg higher, in comparison with the cycle ergometer. By analyzing the two ergometers, it was possible to observe attainment of the same maximum heart rate toward the end of the test (Figure 1). The latter was around 175 beats per minute, which was 24 beats lower, taking account the predicted data from the equation $HR \text{ max} = 220 - \text{age}$. One of the main contributions of this pilot study is the finding that the total time interval of the spiroergometric load test was considerably shorter ($p < 0.05$) on the AirBike ergometer. Specifically, the interval of load was shorter by 379.2 s. The time evolution of load for each athlete is shown on Figure 2.

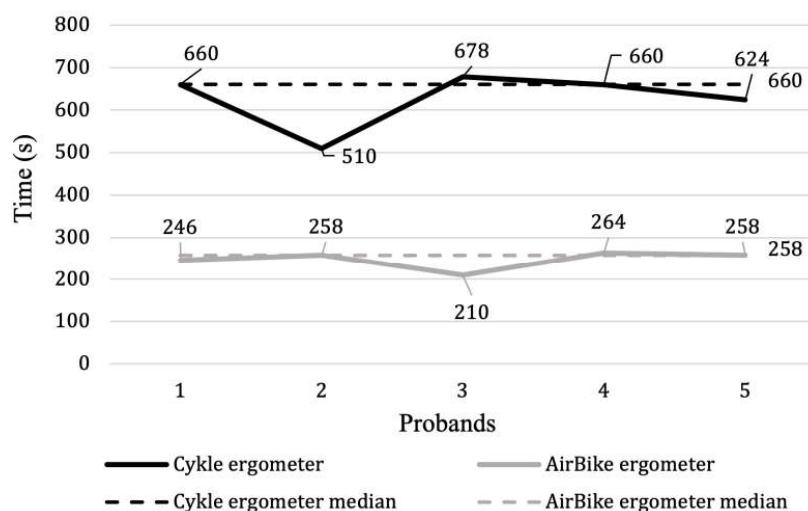


Figure 2: Time evolution of load during tests

For 4 min 12 s, the athletes attained a higher value of VO_{2max} with the same maximum heart rate. The time interval of load during the test demonstrated itself as a limiting factor for the optimization of data collection for power athletes. For combat sports, with an emphasis on mixed martial arts, a time interval up to 5 min modifies athletes' performance. Mutual dependences between variables in relation to the two ergometers are shown in Table 2 through the Spearman correlation coefficient.

Table 2: Values of correlation coefficients for the parameters

	BH	SMM	BM	W max.	W.kg	RER	VO2 max	AB VO _{2max}	AT	AB RPM	AB W max.	t CE	t AB
Age					-0.97					-0.92	-0.92		
BH	0.90	0.90	0.90					0.90	-0.90				
BW				0.90									
SMM				0.90									
BM				0.90									
AB HR max.						-0.92							0.92
W max.									-0.90				
W.kg										0.97	0.97		
RER							-0.89						
VC												0.95	

Note. BH – body height; BW – body weight; SMM – skeletal muscle mass; BM – basal metabolism; AB – AirBike; HR – heart rate; W – watt; max. – maximum; kg – kilogram; RER – respiratory quotient; VC – vital capacity; VO_{2max} – maximal oxygen consumption; AT – aerobic threshold; t – time; CE – cycle ergometer.

When analyzing correlation coefficients, it is possible to observe the highest occurrence of dependence on body height and other somatic variables. With respect to AirBike load, we can expect increased demands on the movement coordination of all extremities, which can be significantly impacted by body height. Nevertheless, maximum performance in watts is highly dependent on body mass and muscle mass proportion. It can be stated that the main factor for the usage of the AirBike ergometer is the age of athletes, as energetic requirements on the body are significantly increased during such a complex movement.

One of the main contributions of this study was the recording of a significantly shorter time interval during the test on the AirBike ergometer to attain maximum heart rate and a related increase in VO_{2max} .

Discussion

The innovation of methodological processes in sports diagnostics is key to obtaining necessary and objective data for the subsequent introduction of these innovative processes into practice. When evaluating power athletes, the emphasis is on sports specialization. In practice, it is possible to distinguish the tested items as laboratory, terrain, and laboratory-terrain. Among our sports, ice hockey is the most common in the current literature. McGuigan (2017) tested the speed-strength ability of ice hockey players in a test by focusing on the upper part of the body versus the lower part of the body. In addition, complex motor tests were applied, as

follows: 1. standing medicineball throw; 2. weightlifting snatch; and 3. weightlifting clean. The 30-s Wingate test, conducted on a skating treadmill, is a specific laboratory–terrain test for ice hockey players. To establish anaerobic performance, the Wingate test can be carried out in conditions close to the real movements of the player on the ice rink. Durocher (2010) tested ice hockey players directly on the ice rink and ensured higher values of $\text{VO}_{2\text{max}}$ than in the laboratory environment or on a skatemill. The $\text{VO}_{2\text{max}}$ value increased up to the period prior to play-offs. During the play-offs, a significant decline in aerobic fitness was observed due to the demanding training and game schedule (Morešćák et al., 2013). According to Leiter et al. (2015), if relative $\text{VO}_{2\text{max}}$ decreases with age, a player's ability to move their respective body mass around the ice may be of concern. Nevertheless, Quinney et al. (2008) observed over a 26-year period that NHL athletes not only showed an increase in $\text{VO}_{2\text{max}}$ but also in peak power output achieved during anaerobic bike testing. Many problems have been identified in the measurement and use of power in strength and conditioning research, as well as problems in the use of the vertical jump as a field test of power.

A critical review of the biomechanics, measurement, and training research does not support this colloquial use of the term “power.” More research is needed to improve our understanding of the domains of muscular strength and neuromuscular performance, as are partial correlation and multiple regression analyses to document the unique associations among these domains, biomechanical variables, training effects, and sport performance. One criticism of the performance calculation technique for these movements alone is that the value does not predict real performance that can be used in sport (Knudson, 2009). Boucher et al. (2020) compared power testing on and off ice by 31 NHL players, finding that vertical and horizontal jumps significantly correlated with the modified skating test, the Sergeant anaerobic test (SAS40), and Reed repeated sprint test (RSS), and correlation depended on player position. In the original study of Watson and Sargeant (1986), which compared the 30-s Wingate test with the Sergeant and Reed skating tests on ice, significant correlation was found for the evaluation of anaerobic capacity. The SAS40 test, consisting of 40 seconds of continuous skating, with the total distance reached measured, is considered a better indicator of anaerobic performance. The Reed test (Reed et al., 1979), is conducted by skating 54 meters at maximum speed every 30 seconds, six times in total. The time obtained in the first lap can be considered a criterion for speed–strength performance and skating skills. Potteiger et al. (2010) discovered a correlation between the first laps in the Reed test and maximum performance in the 30-s Wingate test in terms of kilograms of body mass (W.kg). Based on an evaluation of 45 ice hockey players, it was noted that the relative mean maximum performance evaluated by the 30-s Wingate test did not have a significant relation with performance in the Reed repeated skating test. Statistical meaningfulness of the relation was confirmed through acceleration and maximum speed on ice (Peterson et al., 2016). Specific hockey skating Reed test cannot be swapped for a similar test office (Legerlotz et al., 2022).

The different mechanics of running and cycling compared with skate glide most likely contribute to the different results, as does the external weight of ice hockey equipment. In combat sports, testing is most frequently done with cycle ergometers, but mutual comparison is complicated due to differences in methodological protocols. Cycle ergometer performance of between 455 and 724.5 W was recorded by Sterkowicz et al. (1999). When it comes to other sports, wrestling has demonstrated lower performance values in comparison with judo and taekwondo. In Yoon (2002), wrestlers and boxers had the highest level of maximum oxygen consumption, which ranged from 60.2 to 61.4 ml/kg/min; in contrast, the lowest value has been recorded by elite judo athletes, at 47.3 ml/kg/min (Sbriccoli et al., 2007). Mixed martial arts are a combination of all combat sports, which results in their physiological profile. Gochioco et al. (2010) stated that amateur MMA fighters most resemble judo athletes in terms of their physical appearance. Tested on strength capabilities, judo athletes attained 58.1 ml/kg/min for $\text{VO}_{2\text{max}}$, while wrestlers attained 53.4 ml/kg/min. Diversity in sports specializations and the test protocols used is the main factor for comparing other measured data. For MMA, it is most important to select a method with innovative approach that could be regularly applied in practice. Aerobic fitness should be assessed at least twice a year and preferably before the season, during it, and shortly after it has ended. This would provide baseline information for goal setting; in addition, it would determine whether a player deconditions, maintains, or improves fitness over the season (Leiter et al., 2015). The results of the study by Broich et al. (2012) clearly showed that spiroergometric examinations provide critical information that allows for a more precise description and profile compilation of a player's endurance capacities. Taking the results of spiroergometric testing into account is critical for designing and evaluating player-specific training programs aimed at optimizing each player's performance.

Conclusions

For an objective comparison of two ergometers, the established validity and reliability of using the AirBike as a device for testing and the protocol used are absent in the current literature. Such an approach for repeated measurements is the first step toward modifying and improving on the established methodologies. The time interval required for the implementation of the test is shown to be a determining factor for practical use. From the original 10.44 min on the cycle ergometer, the duration of the test on the AirBike was shortened by 6 min 32 s. Despite the shorter time interval, a 3 ml.kg⁻¹.min⁻¹ higher value of $\text{VO}_{2\text{max}}$ was recorded. It turns out that the AirBike ergometer places increased demands on the coordination of movements and could find its application mainly in the diagnostics of performance and elite athletes. However, the movement of the upper

limbs on the AirBike makes objective measurement of blood pressure indicators impossible. For the combat sports category, a time interval of up to 5 min from the implementation of the test was shown to be a better alternative and during which it would be possible to categorize the performance levels of these athletes with a higher degree of probability. In the case of ice hockey players, their specific activity on the ice surface is not applied to the full extent when using a cycle ergometer, since their upper limbs are not involved. The AirBike creates prerequisites for a more objective assessment of the level of motor fitness, and due to it being impossible to comprehensively assess an athlete's state of health during the examination (e.g., assessment of the pressure response to the load), it nevertheless appears to be an excellent method in addition to the spiroergometric examination on a bicycle ergometer, even for ice hockey players.

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