RESEARCH ARTICLE

Combination of novel and traditional cardiorespiratory indices for the evaluation of adolescent volleyball players

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Abstract

Background: Although cardiopulmonary exercise (CPX) test is an essential tool for the assessment of functional capacity in athletes, limited information exists regarding the cardiorespiratory efficiency in young elite volleyball players. The main objective of the present study was to determine the maximal oxygen uptake (VO_2max) and ventilatory anaerobic threshold (VT) during the CPX test in young male and female volleyball players. Moreover, to describe the behavior of the novel cardiorespiratory optimal point (COP) index and to assess its association with VO_2max and VT.

Methods: Eleven adolescent male (15.18 ± 0.75 years old) and 13 female (14.77 ± 0.44 years old) volleyball players underwent a graded maximal exercise test on a treadmill until exhaustion in order to obtain VO_2max, VT and COP. The COP was set as the lowest ventilation (VE)/VO_2 ratio at a given minute of spiroergometry.

Results: COP values did not differ significantly between the two sexes (19.81 ± 1.29 and 20.44 ± 2.63 in males and females, respectively) and it was achieved at a speed of 3.41 ± 0.89 km/hr in males, and 3.78 ± 0.76 km/hr in females, lower than that achieved at the VT. COP was not correlated with VO_2max (56.32 ± 6.36 ml/kg/min and 44.78 ± 3.65 ml/kg/min) nor with VT (34.81 ± 10.13 ml/kg/min and 34.13 ± 5.87 ml/kg/min) in male and female young volleyball players, respectively.

Conclusions: The novel submaximal cardiorespiratory index of COP does not seem to be associated with the traditional aerobic capacity indices in athletes such as VO_2max and VT. Thus, it probably constitutes a separate parameter that needs to be further evaluated regarding its significance both in clinical evaluation and sports performance assessment of athletes. HIPPOKRATIA 2019, 23(2): 70-74.

Keywords: Cardiorespiratory, optimal point, exercise testing, volleyball, adolescence

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Introduction

Successful exercise training in young players in volleyball provokes the development of primary and special motor skills, harmonious adaptations, and the strength of joints and segments, which are significant elements for obtaining success and high performance in this sport. Athletes, coaches, and sports scientists have a keen interest in measuring body adaptations produced by physical training. For this reason, methods that provide reliable information on athlete's performance during competition or training are needed[1] since athletes are frequently subjected to high volume and intensity training to achieve desirable metabolic, cardiovascular, and neuromuscular adaptations to increase their physical capacity[2]. In order to be effective, a volleyball player needs to be able to demonstrate a wide range of fitness components, such as endurance, speed, power, flexibility, and agility. According to these components, volleyball belongs to mixed aerobic-anaerobic sports. Thus, the measurement of gas exchange during maximal exercise testing is an essential tool for assessing the aerobic and anaerobic functional capacity. Significantly, few and controversial data exist corresponding to cardiorespiratory efficiency indices in young elite volleyball players[3-6]. However, it was suggested that there are some limitations, such as low reproducibility, different techniques, and criteria for identification of both maximal oxygen uptake (VO_2max) and ventilatory threshold (VT) in athletes, remaining when these indices are used for the planning of individualized trainings[7-8]. Recent studies have shown that cardiorespiratory optimal point (COP) measurement, which corresponds to the lowest value of the ventilatory ratio for oxygen (minimal VE/VO_2) throughout a cardiopulmonary exercise (CPX) test, is an objective and stable index, useful in athlete's evaluation[9].

Therefore, the purpose of the present study was to determine VO_2max and VT during maximum exercise testing in young male and female volleyball players. Moreover, to describe the behavior of the novel submaximal index of COP and to assess its association with VO_2max and VT.

Methods

Participants

The study group comprised 11 adolescent male (mean age 15.18 ± 0.75 years old) and 13 female (mean age 14.77 ± 0.44 years old) volleyball players. The participants were a part of the Greek national adolescent volleyball team that originated from Northern Greece. The subjects had no cardiovascular, orthopedic, or other medical problems, and no athlete was excluded. The participants were asked not to change their sleeping, eating, or drinking habits during the study. Nevertheless, all subjects had to avoid drinking any caffeinated and alcoholic beverages or using any ergogenic aids for at least two days before the experimental procedures. All measurements took place in the middle of the competitive season. The protocol of the study is in agreement with the principles of the Declarations of Helsinki (1964), and it was approved by the Ethics Committee of the School of Physical Education & Sport Science of Aristotle University of Thessaloniki. Before data collection, the participants were informed of the requirements of the study and provided written informed consent.

Maximal exercise test

Each volleyball player underwent a graded maximal stress test on a motorized treadmill [h/p/cosmos pulsar, Nussdorf-Traunstein, Germany] in order to obtain VO_2 max, VT, and maximal heart rate (HRmax). Bruce's exercise protocol was performed. Each athlete was exercised until exhaustion in a properly climatized room (23 ^{o}C air temperature, 50 % relative humidity). Breath-by-breath ventilation and gas exchange were continuously analyzed via an automated pulmonary/metabolic gas exchange system (Oxycon Pro-Jaeger, Wurzburg, Germany) during the exercise with the data averaged to five seconds for analysis. The following criteria were used to document that VO_2max was achieved: i) a lack of increase in VO_2 upon an increase in work rate, ii) respiratory exchange ratio >1.10, and iii) an HRmax higher than 85 % of the age-predicted value (HRmax =220 - age). VO_2max was recorded as the highest oxygen consumption value in the final 30 seconds of the test. The VT was determined according to the V-slope method as the point at which an abrupt increase of ventilation (VE) was observed, and a sustained increment in VE/VO_2 ratio occurred. Moreover, the velocity and the VO_2 at the VT point were also detected. HR responses were monitored continuously during the maximal stress test.

Determining the COP

The COP was obtained by identifying the lowest VE/VO_2 ratio at any given minute of the CPX test, being, thus, a non-dimensional parameter. Additionally, the VO_2 and the running velocity in the treadmill protocol at COP were recorded.

Statistical analysis

All values are expressed as mean ± standard deviation (SD). The normality of the sample distribution was ascertained with the Shapiro-Wilk test, and independent samples t-test was utilized to determine differences between male and female volleyball players. Correlation analysis was performed according to Pearson's since there was a normal distribution in the samples. The statistical analysis was performed with IBM SPSS Statistics for Windows, Version 25.0. (IBM Corp., Armonk, NY, USA). Significance for all tests was set *a priori* at $p <0.05$.

Results

The anthropometric data and the training characteristics of the young players did not differ significantly between the two sexes except the resting values of systolic blood pressure (Table 1). The results of the maximal CPX on the treadmill are presented in Table 2. There was a tendency for higher maximal systolic blood pressure (sBPmax) by approximately eight mmHg in males compared to females while the HR at the VT tended to be higher in females by approximately 12 beats/min compared to males, but these findings were not statistically significant ($p =0.065$ and $p =0.059$, respectively). The COP values

Table 1: Physical and training characteristics of the 11 adolescent male and 13 female volleyball players who underwent maximal exercise treadmill test.

	Total (n =24)	Males (n =11)	Females (n =13)	p
Age (years)	14.95 ± 0.62	15.18 ± 0.75	14.77 ± 0.44	0.108
Height (cm)	172.75 ± 5.67	174.36 ± 6.55	171.38 ± 4.65	0.207
Weight (cm)	62.08 ± 7.18	64.45 ± 8.80	60.07 ± 4.99	0.140
BSA (m^2)	1.73 ± 0.12	1.78 ± 0.14	1.70 ± 0.08	0.144
Years of training	4.41 ± 1.24	3.33 ± 1.53	4.78 ± 0.97	0.078
Training sessions/wk	5.50 ± 0.74	5.55 ± 0.89	5.46 ± 0.66	0.777
Training mins/wk	115.50 ± 21.81	108.75 ± 20.83	120.00 ± 22.16	0.270
HR_{rest} (beats/min)	71.83 ± 10.62	72.55 ± 13.66	71.23 ± 7.75	0.770
sBP_{rest} (mmHg)	114.58 ± 7.77	119.09 ± 7.35	110.77 ± 10.17	**0.034**
dBP_{rest} (mmHg)	70.42 ± 4.40	71.36 ± 5.05	69.62 ± 3.80	0.344

Values are expressed as mean ± standard deviation. n: number, BSA: body surface area, HR_{rest}: heart rate at rest, sBP_{rest}: systolic blood pressure at rest, dBP_{rest}: diastolic blood pressure at rest.

Table 2: Cardiopulmonary exercise data of the 11 adolescent male and 13 female volleyball players who underwent maximal exercise treadmill test.

	Total (n =24)	Males (n =11)	Females (n =13)	p
HR_AT (beats/min)	168.08 ± 15.96	161.45 ± 15.94	173.69 ± 14.22	0.059
HR_{max}	191.71 ± 6.66	192.36 ± 7.15	191.15 ± 6.47	0.668
Time to exhaustion (min:sec)	12:07 ± 01:14	13:09 ± 00:56	11:14 ± 00:35	**0.001**
sBP_{max} (mmHg)	153.33 ± 10.80	157.73 ± 10.34	149.62 ± 10.10	0.065
dBP_{max} (mmHg)	63.33 ± 9.05	65.00 ± 8.06	61.92 ± 9.90	0.419
VO_{2max} (ml/kg/min)	50.07 ± 7.68	56.32 ± 6.36	44.78 ± 3.65	**0.001**
VO_{2max} (ml/min)	3108.71 ± 595.37	3606.73 ± 464.03	2687.31 ± 283.23	**0.001**
VO_{2max} predicted (%)	113.11 ± 12.78	121.42 ± 11.04	106.08 ± 9.72	**0.002**
VO_{2AT} (ml/kg/min)	34.44 ± 7.92	34.81 ± 10.13	34.13 ± 5.87	0.840
VO_{2AT} (ml/min)	2104.21 ± 434.27	2204.18 ± 504.26	2019.62 ± 364.21	0.310
$Velocity_{AT}$ (km/hr)	6.29 ± 0.70	6.21 ± 0.87	6.35 ± 0.54	0.624
RER_{max}	1.20 ± 0.08	1.19 ± 0.07	1.21 ± 0.09	0.525
RER_{AT}	0.97 ± 0.02	0.98 ± 0.02	0.97 ± 0.02	0.867
COP (VE/VO_2)	20.15 ± 2.11	19.81 ± 1.29	20.44 ± 2.63	0.480
VO_{2COP} (ml/kg/min)	24.05 ± 11.04	27.32 ± 12.84	21.29 ± 8.84	0.189
$Velocity_{COP}$ (km/hr)	3.61 ± 0.83	3.41 ± 0.89	3.78 ± 0.76	0.289
HR_{COP} (beats/min)	132.71 ± 16.77	121.73 ± 9.77	142.00 ± 15.97	**0.001**

Values are expressed as mean ± standard deviation. n: number, HR_{AT}: heart rate at the anaerobic threshold, HR_{max}: maximal heart rate, sBP_{max}: maximal systolic blood pressure, dBP_{max}: maximal diastolic blood pressure, VO_{2max}: maximal oxygen uptake, VO_{2AT}: oxygen uptake at the anaerobic threshold, $Velocity_{AT}$: velocity at the anaerobic threshold, RER_{max}: maximal respiratory exchange ratio, RER_{AT}: respiratory exchange ratio at the anaerobic threshold, COP: cardiorespiratory optimal point, VO_{2COP}: oxygen uptake at the cardiorespiratory optimal point, $Velocity_{COP}$: velocity at the cardiorespiratory optimal point, HR_{COP}: heart rate at the cardiorespiratory optimal point.

did not differ between the two sexes.

There were no significant correlations between COP (minimum VE/VO_2) and any measured cardiorespiratory parameter. Nevertheless, the ml/kg/min values of VO_2 at the COP time point (VO_{2COP}) were significantly correlated with VO_2max when expressed in ml/kg/min ($r = 0.564$, $p = 0.004$) as well as with VO_2 (ml/kg/min) at the anaerobic threshold (VO_2AT) ($r = 0.579$, $p = 0.003$).

Discussion

Volleyball is a sport that incorporates both aerobic and anaerobic components. Sufficient cardiorespiratory fitness is necessary for long-duration matches. The aerobic performance in sport endurance events depends on three significant components: VO_2max, VT, and work economy. VO_2max corresponds to the maximal oxygen consumption that can be measured during an incremental exercise test. Previous studies in soccer and volleyball players have shown a significant relationship between VO_2max and distance covered during a match[10]. Additionally, Haritonidis et al showed that VO_2max in elite male volleyball players presents significant variation from 47.0 ml/kg/min up to 51.5 ml/kg/min during the annual training season, concluding that the physiological demands of the game in combination to the training plan for increased performance according to the targeted goals, specify the level of aerobic capacity during the sports season[10].

There is limited information about the effect of exercise training on cardiorespiratory adaptation in elite adolescent volleyball players. Aerobic capacity in young athletes is mainly dependent on the load of training. Faizrakhmanov et al, showed that the growth of skills among young volleyball players is largely due to the increase in the level of special endurance[11]. An effective system of control and development of individual endurance plays an important role in this regard. Such a system for young volleyball players has only partially been developed; the specifics of its application in age groups of 13-18 years are not sufficiently defined and specified[11]. Distinctive endurance of young volleyball players is characterized by a complex of major unique physical qualities and functional capabilities that are necessary for performing technical and tactical actions in the process of training and competitions with high efficiency and economy. Complex assessment of the individual endurance consists of indicators of jumping, speed, and game endurance[4,12]. From a general perspective, studies have shown that a player's best performance is approximately eight to twelve years after the theoretical specialization age (16 years old or later) and even later for setters and liberos. The so-called "ten-year rule" is not followed when it is taken as a reference from the theoretical starting age in volleyball (nine to twelve years old). It seems that long specialized training after general individual training is necessary. The acquisition of training and competitive experience during a minimum of 10 to 12 years is necessary to achieve peak performance, in addition to the ideal anthropometrics and physical capabilities[13-14]. However, it should also be borne in mind that there may be an underlying genetic predisposition of elite athletes. The assessment of VO_2max at a laboratory set is considered as the ideal process of measuring maximal aerobic capacity (gold standard), and it is a common and reliable ergometric tool in the functional evaluation of athletes. In the present study, VO_2 max has been found using a treadmill ergometer. The mean VO_2max for study subjects was found to be 50.1 ml/kg/min. The VO_2 max in male players was significantly higher compared to females. Taware et al have estimated the mean VO_2max of volleyball players aged 17-25 years old to be 44.55 ml/kg/min[15], while Smith et al have found VO_2 max of 56.7 ml/kg/min, in Canadian national volleyball team and 50.3 ml/kg/min in university volleyball players[16]. Moreover, Milenković et al showed that the volleyball players had lower VO_2max values in comparison with the handball players (45.5 ml/kg/min vs 51.9 ml/kg/min), which can be explained by the more aerobic character of the second sport[17].

However, the activity elicited during a VO_2max test does not reflect the high-intensity intermittent nature of volleyball performance. Therefore, VO_2max assessment does not identify particular components of volleyball players' physical condition and parameters of their performance during the game but can provide significant input about the physical fitness of a player, as well as a comparative analysis between subgroups. These admissions, as well as the fact that VO_2max testing is moderately unsuitable for a frequent application in volleyball teams, suggest sports scientists should use maximal oxygen uptake assessment during periods of the season when substantial changes in fitness are expected. Methodological issues in measurement and criteria of VO_2max and VT establishment along with moderate reproducibility of these indices, restrain their wide implementation as a typical ergometric process[8,18]. Moreover, the structure of the training schedule may be compromised by these aspects, thus threatening the achievement of the training goals[19].

The lactate threshold represents a useful tool in terms of evaluating the efficiency of training endurance programs in steady-state exercise patterns. Nevertheless, volleyball does not constitute a steady-state form of exercise, and the utility of lactate acidosis evaluation in this sport is in doubt. Thus, the measurement of lactate accumulation in volleyball players should not be preferred in this sport discipline since it better corresponds to a general physical condition assessment rather than volley-specific performance parameters. During an exercise of incremental intensity, the point that lactate acidosis shows an abrupt increase corresponds to the anaerobic threshold, and it is usually expressed in terms of heart rate, velocity, and oxygen uptake. The anaerobic threshold in absolute values of oxygen uptake (ml/min) is of paramount significance, but it is strongly correlated with VO_2max[20]. The exercise intensity of a typical volleyball game is similar to the anaerobic threshold due to the time duration of the match. Nevertheless, during the game, the volleyball players usually play at intensities above or below the threshold, and just for short periods of the game, they practice at intensities corresponding to the anaerobic threshold due to the nature of this sport[20]. In our study, the anaerobic threshold was found to be 34.4 ml/kg/min (68.7 % of VO_2max). In males, it was lower as a percentage of VO_2max in comparison to females (61.8 vs 76.1 %, respectively), while there were no differences in absolute VO_2 values at VT between male and female volleyball players (34.8 vs 34.1 ml/kg/min, respectively).

Work economy is defined as oxygen cost at a submaximal exercise intensity, and as much as 20 % difference in the economy has been found in trained endurance athletes at similar VO_2max levels. Nevertheless, limited information exists about the effect of enhanced work economy on volleyball performance. Therefore, future studies are needed to determine the effects of the exclusively improved economy on the volley players' performance.

The ventilatory ratios typically show a U-shape during an incremental exercise test, marked particularly by notable efficiency at submaximal intensities of exercise. In the literature, there are many well established ventilatory markers extracted by an incremental exercise; nevertheless, the significance of the lowest VE/VO_2 ratio at any given minute of a CPX test performed in a ramp protocol, remains controversial. Ramos et al described recently a new index, COP, which is the moment at which VE/VO_2 minimum occurs, representing as the best association or integration between the respiratory and cardiovascular systems or ventilation-perfusion. Basically, the COP during a gradual CPX test is consistent with the phase where there is less VE for a liter of oxygen to be consumed[21].

It is worth noting that the application of a maximal CPX test does not constitute a necessary condition in order to detect the COP contrary to the majority of the exercise ventilatory indices. It is reasonably assumed that the COP is easily and accurately measured since it is much less affected by the ergometric staff (e.g., verbal encouragement during a maximal effort) as well as by other parameters such as the workload characteristics of the ramp protocol or the degree of the athlete's effort for an exhaustive test. Therefore, it seems useful to study the COP in healthy individuals, providing practical information for the application of this index in CPX testing evaluation, and decoding the physiological meaning of this marker. Ramos et al have supported that this variable has some advantages when compared to others obtained during a CPX test, such as VO_2max, the oxygen pulse curve, and the anaerobic threshold, which are often addressed in other studies related to spiroergometry and presented as good prognostic health indicators[21,22].

In our study, the COP was estimated to be 19.8 ± 1.3 in male and 20.4 ± 2.6 in female volleyball players. In soccer players, Grüne de Souza e Silva et al, found the COP to be 18.2 ± 2.1, achieved at a speed 4.3 ± 1.4 km/hr, lower than that achieved at the VT[9]. They described that this value was the 50^{th} percentile of the levels noticed for healthy male sedentary age-matched subjects in an earlier study and that only 4 % of the soccer players had a COP value over 22, which is considered as the optimal predictive value, suggesting that those soccer players had a privileged circulation-respiration interaction, probably more economical at the submaximal exercise. Interestingly, they demonstrated that the COP is moderately correlated with VO_2max ($r = -0.47$, $p < 0.001$) and weekly correlated with maximum VE ($r = -0.14$, $p < 0.001$). These findings may reasonably justify the aspect that the COP probably constitutes an independent marker of VO_2max and VE with prospects of further utilization in the understanding of a CPX test physiological outcomes. The mean value of COP in our study was below 20.5, considerably under the suggested cutoff point of 22 for optimal clinical prognosis. Nevertheless, we did not find any association between COP and VO_2max or VT in male and female volleyball players. Thus, it probably constitutes a separate parameter that needs to be further evaluated regarding its significance both in clinical evaluation and sports performance assessment of athletes. Additionally, the results of the study should be interpreted in light of the relatively small size of the sample, and further well-designed studies are also needed in other sport-specific populations.

Conclusions

In this study, both novel and well-established cardiorespiratory indices, following maximal exercise treadmill test, were described in young volleyball players. The traditional aerobic parameters of VO_2max and VT were found to be at the higher margins of the existed relevant literature, indicating an increased aerobic capacity. However, the submaximal cardiorespiratory index of COP does not seem to be associated with the above aerobic capacity indices in athletes. The investigation of this cardiorespiratory novel index in athletes might contribute to providing relevant data on the health of players, planning, and follow-up of the training effects, also might being useful for the early selection of athletes.

Conflict of interest

The authors declare no conflicts of interest.

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