association between sub-maximal and maximal measures of aerobic power in female adolescents

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Introduction

While higher spectrum is associated with wellbeing many national and international organizations that focus on health, e.g. the American College of Sports Medicine (Ehrman, 2010) and the World Health Organization (World Health Organization, 2010), recommend exercise interventions targeting CRP. Because this health-related fitness parameter must be monitored periodically to evaluate its progress, appropriate tests should be applied. Consequently, the lower spectrum of cardiorespiratory power (CRP) is associated with heart and pulmonary diseases (chronic obstructive pulmonary disease, coronary heart disease, chronic heart failure, and intermittent claudication) (Pedersen and Saltin, 2006), its higher spectrum is linked not only to the absence of the aforementioned diseases, but also to wellbeing. Maximal oxygen uptake, i.e., the maximal quantity of oxygen received by human body through the respiratory system and transferred from lungs to tissues through the cardiovascular system where it is consumed, is regarded as the gold standard in the assessment of CRP.

Nonetheless, the need for expensive equipment, a well-trained staff, and maximal effort that reaches exhaustion from participants raises the question for the usage of alternative assessment methods. It is thought that sub-maximal measures overcome certain limitations connected with maximal testing (Noonan and Dean, 2000); they are easier to administer, less expensive, and they demand

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much less effort from participants. Physical working capacity at a heart rate (HR) of 170 beats per minute (PWC_{170}) is a sub-maximal test, which is performed on a cycle ergometer. The test evaluates the power corresponding to HR 170 beats per minute (bpm), i.e. the higher the PWC170, the higher the CRP. The YMCA Step Test estimates the HR during the first minute of recovery after 3 minutes of stepping up and down, i.e. the lower the heart rate, the higher the CRP. In addition to the recording of the recovery HR, the HR at the end of the 3-minute step test can be used as an index of CRP, too. To apply such measures in different populations, two parameters should be chiefly considered, validity and reliability. Validity is the degree to which a test measures what it purports to measure, while reliability is its characteristic to yield the same results on successive trials (Thomas et al, 2011). The validity of PWC_{170} was already examined in 12-year-old non-Caucasian females against $VO2_{max}$ (Mahoney, 1992) and 15.6-year-old Caucasian female adolescents (Boreham et al, 1990). Additional relevant research conducted on schoolchildren did not discriminate between girls and boys and was excluded from further analysis (Buono et al, 1991).

Two null hypotheses were examined: first, that there was no agreement between test- retest of sub-maximal measures with interval of a week (reliability) and second, that there was no association between indices of sub-maximal measures and $VO2_{max}$ (validity). Nevertheless, the aim of the study was not only to reject the null hypotheses and adopt their alternative, but to also achieve proper levels of affinity of the above parameters in order to ground validity and reliability in light of minimal values suggested by previous research (Badland and Schofield, 2006, Baranowski and de Moor, 2000, Kurtze et al, 2007). Particularly, the acceptable level of intraclass correlation coefficient was proposed to be higher than 0.61 (Badland and Schofield 2006, Baranowski and deMoor, 2000). At least moderate ($0.30 < r < 0.50$) correlates with the criterion measures were suggested to lead to the validation of an instrument (Kurtze et al, 2007).

Aim of Work

To examine the association between two sub-maximal (physical working capacity at a heart rate of 170 (PWC_{170}) on cycle ergometer test and YMCA Step Test) and maximal measures (maximal oxygen uptake ($VO2_{max}$) of aerobic power, as well as to study the repeatability of the aforementioned sub-maximal measures in physically active female adolescents.

Material and Methods

Participants and Procedures. Ten female adolescents, aged 13.4 ±0.7 years old, all members of a local track and field Ahly club, volunteered for this study. They visited our laboratory twice, with an interval of a week, they were informed of the protocols, and their parents provided oral informed consent. During their first visit, body composition, resting heart rate, blood pressure, and anthropometric data were obtained followed by a guided 15-minute warm-up (Table 1). Then, physical working capacity at a heart rate of 170 (PWC_{170}) and the step test were performed.

During their second visit, the same procedures were repeated and, additionally, after a 15- minute break, a graded exercise test was performed.

Protocols and Equipments. Height and body mass were measured using an InBody an electronic scale. PWC_{170} was performed according to Eurofit guidelines (Eurofit, 1988). YMCA Step Test was performed in a 0.3 m height step for 3 minutes using a 24 ascent/ min cadence (Golding, 2000). A graded exercise test on a cycle ergometer (Ergomedics 828, Monark, Sweden), in which the initial workload was 1.5 W/kg, and was increased by 20 W every minute until exhaustion (Heller, 2005), was performed. Minute ventilation and oxygen uptake were recorded by a gas analyzer (Fitmate Pro, Cosmed, Italy). Anaerobic threshold was identified from ventilatory threshold, i.e. the relationship between minute ventilation and oxygen uptake. During test a cadence of 80 revolutions per minute was maintained through two means: visual contact with the monitor embodied in the cycle reporting cadence and the audio signal from a metronome set at 80 beats per minute. The duration of every flywheel revolution in cycle ergometer tests was measured with the help of electronic sensors; the power output of every revolution was computed by specialized software (Papadopoulos et al, 2009).

Blood samples were taken 5 minutes after termination of test, and lactate concentration was analyzed. Lactate concentration was employed as a criterion of $VO2_{max}$ achievement (accepted values > 9 mmol/L).

Predicted maximal heart rate was calculated by the formula $HR_{max,predicted}$ = 208 - 0.7 °— age (Tanaka et al, 2001) and it was employed as a criterion of $VO2_{max}$ achievement, as well as an index of motivation level.

Statistical procedures and data analysis. All data were presented as mean ± standard deviation. Data sets were checked for normality using the Shapiro-Wilk normality test and visual inspection. Student pair t test was employed to compare values between trials. Pearson product moment correlation coefficient (r) was used to examine the association between $VO2_{max}$, PWC_{170}, and step test and therefore to ground the validity of sub-maximal measures. Intraclass correlation coefficient (ICC) was employed to examine the reliability of sub-maximal measures outcome and it was expressed in 95% lower and upper bounds of confidence intervals (CI). Student t test was employed to examine the differences between trials. Significance level was set at P = 0.05. Statistical analyses were performed using SPSS version17.0.

Results

During the second visit to the laboratory, all sub-maximal indices improved, either significantly (PWC_{170} t10 = 2.55, p = 0.03; PWC_{170} expressed in relative to body mass values, $rPWC_{170}$, t10 = 2.62, p = 0.03) or non-significantly (HR at the end of step test t10 = 0.41, p = 0.69; recovery HR after step test t10 = 1.75, p = 0.11). With the exception of systolic arterial pressure (BP_s t=-2.71, p = 0.02), diastolic pressure and resting heart rate similar (BP_d t = 0.31, p = 0.76; HR_{rest} t = 0.73, p = 0.48). Considering the reliability of sub-maximal measures of CRP, ICC was 0.89 (95% CI 0.55- 0.97) in

PWC_{170} and 0.91 (95% CI 0.65-0.98) in $rPWC_{170}$, while it was 0.69 (95% CI -0.27-0.92) at the end of step test and .0.78 (95% CI 0.11-0.95) at the end of the first minute of recovery after step test (Table 2).

Table (1)
Mean values (±SD) of cardiorespiratory parameters of participants (n = 10)

Variable	Pre	Post	cardiorespiratory
BP_s (mmHg)	122.9 ± 9.1	112.7 ± 11.9*	0.751
BP_d (mmHg)	60.8 ± 9.0	60± 8.1	0.711
HR_{rest} (bpm)	79.8 ± 12.3	77.4± 10.4	0.820
Step $test_0$ (bpm)	158.9 ± 16.6	157± 14.7	0765
Step $test_1$ (bpm)	106.7 ± 22.1	97.4± 16.8	0.732
PWC_{170} (W)	87.00 ± 23.97	13.06± 16.21*	0.754
$rPWC_{170}$ (W/kg)	1.81 ± 0.51	1.56 ± 0.30*	0.755
	Post		
$VO2_{max}$ (mL/min/kg)	36.80 ± 5.09		
Ve (L/min)	59.43 ± 10.64		
HR_{max} (bpm)	195.0 ± 10.5		
HR_{thr} (bpm)	160.6 ± 10.9		
Lactate (mmol/L)	10.0 ± 3.1		
$HR_{max,pred}$ (bpm)	198.6 ± 0.5		
$HR_{max}/HR_{max,pred}$%	98.2 ± 5.2		

Legend: BP_s – Systolic blood pressure; BP_d – Diastolic blood pressure; HR_{rest} – Heart rate in rest; Step $test_0$ – Heart rate at the end of step test; Step $test_1$ – Heart rate at the first minute of recovery after step test; PWC_{170} – Physical working capacity in heart rate 170 beats per minute; $rPWC_{170}$ – PWC_{170} relative to body mass; Ve – Pulmonary ventilation; HR_{max} – Maximal heart rate; HR_{thr} – Heart rate at anaerobic threshold; $HR_{max,pred}$

– Maximal heart rate predicted from age; $*p<0.05$.

Heart rate at the end of graded exercise test reached over 98% of predicted value based on age, and lactate levels were in accepted levels. Therefore, end values of this test were considered maximal. PWC_{170} was associated significantly with $VO2_{max}$ in absolute values (r = 0.65, p = 0.04), but not with $VO2_{max}$ in relative to body mass values (r = 0.44, p = 0.20). The corresponding relationships between $rPWC_{170}$ and $VO2_{max}$ were r =.39 (p = 0.27) and r = 0.60 (p = 0.06). Heart rate at the end of the step test was non-significantly related to $VO2_{max}$ in both absolute and relative values (r = -0.53, p = 0.12 and r = -0.61, p = 0.06), whereas respective values of heart rate at the end of the first minute after step test were r = -0.72 (p = 0.02) and r = -0.69 (p = 0.03).

Discussion

It was examined whether the findings between trials, separated by one week, differed? Participants had better performance in all sub-maximal CRP indices during the second trial. This improvement was either statistically significant (PWC_{170} test) or non-significant (step test). Difficulty in pedaling at the required cadence and HR elevation from anxiety were mentioned previously as potential reasons for the discrepancy between maximal test and cycle ergometer measures based on HR (Mahoney, 1992). However, adolescents were more accustomed to cycling and possessed a better sense of rhythm. Thus, it was proposed that the explanation for the lower HR responses to the same workloads during the second trial were attributed to both learning effect and lowered anxiety, and not to improvement of CRP. Consequently, these measures were acceptable to be applied in a sample of female adolescents to be tested once. However, if the purpose was to follow CRP longitudinally, a familiarization session was recommended.

The reliability of step test and physical working capacity at a heart rate of 170 bpm and their validity against $VO2_{max}$ were also examined. ICC reached such levels in all sub-maximal indices, which grounded their reliability regarding desirable levels (> 0.61) (Badland and Schofield, 2006), Baranowski and de Moor, 2000). Higher scores of ICC were observed in absolute and relative PWC_{170} than in step test, suggesting PWC_{170} to be more reliable than step test. Correlation between these measures and $VO2_{max}$ ranged between 0.39 and 0.65, and were in agreement with suggested levels (at least 0.30 < r < 0.50 correlates with the criterion measures) (Kurtze et al, 2007). Similar association between PWC_{170} and $VO2_{max}$, estimated by graded exercise test in treadmill, was observed in non-Caucasian female children (r = 0.54, n.s.; N = 8, aged 12 years, VO2peak 38.5 ± 4.4 mL/min/kg, PWC170 1.35 ± 0.42 W/kg) (Mahoney, 1992), and higher in Caucasian female adolescents (r = 0.84, p < 0.05; N = 18, aged 15.4 ± 0.7 years, $VO2_{max}$ 42.6 ± 5.8 mL/min/kg, PWC_{170} 1.86 ± 0.39 W/kg) (Boreham et al, 1990).

PWC_{170} and YMCA step test proved to be valid and reliable assessment methods of CRP in female adolescents, and they were recommended for further use. Recent findings, which revealed a decrease in CRP of girls during the last two decades, highlighted the need for monitoring using this physical fitness parameter (Saczuk and Wasiluk 2010). CRP was inversely associated with BMI, it was lower in children and adolescents with higher BMI (Aires et al, 2010-Dumith et al,2010), Dwyer et al,2009, Huang and Malina, 2010), and it was in close relationship with the parameters consisting the pediatric metabolic syndrome (Brambilla and Pietrobelli, 2009). Increased risk for cardiovascular disease was found among adolescents with low CRP (Lobelo et al, 2010). Children with chronic diseases had lower CRP than healthy controls (Maggio et al, 2010). Regarding the prevalence of inactivity (Nikolaidis, 2009) and obesity (Nikolaidis, 2010, Nikolaidis, 2011), particular levels of physical activity should be attained in order to have healthy CRP (Martinez, et al 2010). Therefore, the development of sub-maximal measures that are easy to be administered with low cost to large numbers of participants without demanding maximal effort, might contribute to better screening of CRP, especially in the context of its inverse association with many diseases. Since it has been shown that the level of exercise participation (Nikolaidis, 2011) and the response to exercise intervention is influenced partially (approximately 50%) by heredity (Bouchard et al, 1999), the effectiveness of an exercise intervention should be monitored periodically, where sub-maximal measures proved to be valid and reliable important assessment tool.

The number of participants in our study (n = 10) presents a limitation of our findings. This drawback has already been identified in previous relevant studies (n = 18, aged 15.4 years, (Boreham, et al, 1990); n = 9, aged 12 years, (Mahoney, 1992). It could be partially attributed to the inherent limitations of laboratory exercise testing, especially in child and adolescent populations.

Conclusions

1. Both the 170 capacity test and the step test have proved to be reliable and consistent for physically active female adolescents.

2 - There is a relationship between the maximum and minimum capacity of the air force of female adolescents.

Recommendations

1- We encourage the widespread use of cardiovascular testing.

- Familiarity with the testing procedures must be confirmed to minimize the height of the heartbeat due to anxiety.

2- To benefit from the results of the research in assessing the maximum and minimum level of air power in adolescent females.

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