Association between submaximal and maximal measures of aerobic power in female adolescents

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Summary

Study aim: To examine the association between two submaximal (physical working capacity at a heart rate of 170 (PWC170) on cycle ergometer test and YMCA Step Test) and maximal measures (maximal oxygen uptake (VO2max)) of aerobic power, as well as to study the repeatability of the aforementioned submaximal measures in physically active female adolescents.

Material and methods: Ten female adolescents, aged 13.4 ± 0.7 years old, all members of a local track and field sport club, performed the PWC170 and YMCA Step Test twice. The tests were separated by an interval of one week. During the second laboratory visit, VO2max was measured during a graded exercise test.

Results: Considering the repeatability of submaximal measures, intraclass correlation coefficient was 0.89 (95% CI 0.55-0.97) and 0.91 (95% CI 0.65-0.98) in absolute and relative to body mass values of PWC170, while it was 0.69 (95% CI -0.27-0.92) with regard to heart rate 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. PWC170 was associated significantly with VO2max in absolute values (r = 0.65, p = 0.04), but not with VO2max relative to body mass values (r = 0.44, p = 0.20). The corresponding relationships between relative PWC170 and VO2max were r = 0.39 (p = 0.27) and r = 0.60 (p = 0.06). Heart rate at the end of the step test was non-significantly related to VO2max 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).

Conclusion: These submaximal measures appeared to be valid and reliable, and they were recommended for further use in similar population with the assumption that a familiarization session was preceded.

Key words: Cardiorespiratory power– Maximal oxygen uptake– Test-retest

Introduction

While 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) [27], its higher spectrum is linked not only to the absence of the aforementioned diseases, but also to well-being. Consequently, many national and international organizations that focus on health, e.g. the American College of Sports Medicine [10] and the World Health Organization [31], recommend exercise interventions targeting CRP. Because this health-related fitness parameter must be monitored periodically to evaluate its progress, appropriate tests should be applied.

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 raise the question for the usage of alternative assessment methods. It is thought that submaximal measures overcome certain limitations connected with maximal testing [24]; they are easier to administer, less expensive, and they demand much less effort from participants.

Physical working capacity at a heart rate (HR) of 170 beats per minute (PWC170) is a submaximal 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.
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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 [30]. The validity of PWC170 was already examined in 12-year-old non-Caucasian females against VO2max [18] and 15.6-year-old Caucasian female adolescents [4]. Additional relevant research conducted on schoolchildren did not discriminate between girls and boys and was excluded from further analysis [5].

Two null hypotheses were examined: first, that there was no agreement between test-retest of submaximal measures with interval of a week (reliability) and second, that there was no association between indices of submaximal measures and VO2max (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 [2,3,16]. Particularly, the acceptable level of intraclass correlation coefficient was proposed to be higher than 0.61 [2,3]. At least moderate (0.30 < r < 0.50) correlates with the criterion measures were suggested to lead to the validation of an instrument [16].

Material and Methods

Participants and procedures. Ten female adolescents, aged 13.4 ±0.7 years old, all members of a local track and field sport 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.

| Variable             | Pre        | Post – Pre difference |
|----------------------|------------|-----------------------|
| Body height (cm)     | 161.0 ± 4.3| 0.2 ± 0.6             |
| Body mass (kg)       | 48.5 ± 6.6 | 0.3 ± 0.4             |
| BMI (kg/m²)          | 18.67 ± 2.12| 0.06 ± 0.15          |
| Body fat (%)         | 20.94 ± 3.50| -0.02 ± 1.16         |

Protocols and equipment. Height and body mass were measured using a stadiometer (SECA, Leicester, UK) and an electronic scale (HD-351, Tanita, Illinois, USA), respectively. Body fat percentage was calculated from the sum of 10 skinfold sites using a skinfold caliper (Harpenden, West Sussex, UK), based on the formula proposed by Parizkova [26]. Body circumference was measured using a measuring tape; humerus and femur biepicondylar breadth were assessed by caliper (Anthropometer 01291, Lafayette, USA).

PWC170 was performed according to Eurofit guidelines [11]. YMCA Step Test was performed in a 0.3 m height step for 3 minutes using a 24 ascent/min cadence [12]. 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 [13], 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 [25]. Blood samples were taken 5 minutes after termination of test, and lactate concentration was analyzed (Accutrend, Roche, Germany). Lactate concentration was employed as a criterion of VO2max achievement (accepted values > 9 mmol/L). Predicted maximal heart rate was calculated by the formula HRmax,predicted = 208 - 0.7 × age [29] and it was expressed in 95% lower and upper bounds of confidence intervals (CI). Student pair t test was employed to compare values between trials. Pearson product moment correlation coefficient (r) was used to examine the association between VO2max, PWC170, and step test and therefore to ground the validity of submaximal measures. Intraclass correlation coefficient (ICC) was employed to examine the reliability of submaximal 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 α = 0.05. Statistical analyses were performed using SPSS v17.0.
**Results**

During the second visit to the laboratory, all submaximal indices improved, either significantly (PWC\textsubscript{170}, \( t_0 = 2.55, p = 0.03; \) PWC\textsubscript{170} expressed in relative to body mass values, rPWC\textsubscript{170}, \( t_0 = 2.62, p = 0.03) or non-significantly (HR at the end of step test \( t_0 = 0.41, p = 0.69; \) recovery HR after step test \( t_0 = 1.75, p = 0.11)$. With the exception of systolic arterial pressure (BP\textsubscript{s} \( t = -2.71, p = 0.02$), diastolic pressure and resting heart rate similar (BP\textsubscript{d} \( t = 0.31, p = 0.76)$; HR\textsubscript{rest} \( t = 0.73, p = 0.48)$). Considering the reliability of submaximal measures of CRP, ICC was 0.89 (95% CI 0.55-0.97) in PWC\textsubscript{170} and 0.91 (95% CI 0.65-0.98) in rPWC\textsubscript{170}, while it was 0.69 (95% CI -0.27-0.92) at the end of step test and .78 (95% CI 0.11-0.95) at the end of the first minute of recovery after step test (Table 2).

**Table 2.** Mean values (±SD) of cardiorespiratory parameters of participants (\( n = 10$)

| Variable               | Pre            | Post – Pre difference | Post difference |
|------------------------|----------------|-----------------------|-----------------|
| BP\textsubscript{s} (mmHg) | 122.9 ± 9.1    | -10.2 ± 11.9*         |                 |
| BP\textsubscript{d} (mmHg) | 60.8 ± 9.0     | -0.8 ± 8.1            |                 |
| HR\textsubscript{rest} (bpm) | 79.8 ± 12.3   | 2.4 ± 10.4            |                 |
| Step test\textsubscript{a} (bpm) | 158.9 ± 16.6 | -1.9 ± 14.7           |                 |
| Step test\textsubscript{b} (bpm) | 106.7 ± 22.1 | -9.3 ± 16.8           |                 |
| PWC\textsubscript{170} (W) | 87.0 ± 23.97  | 13.06 ± 16.21*        |                 |
| rPWC\textsubscript{170} (W/kg) | 1.81 ± 0.51  | 0.25 ± 0.30*          |                 |
| VO\textsubscript{2max} (mL/min/kg) | 36.80 ± 5.09 |                   |                 |
| Ve (L/min)            | 59.43 ± 10.64 |                      |                 |
| HR\textsubscript{max} (bpm) | 195.0 ± 10.5  |                      |                 |
| HR\textsubscript{rest} (bpm) | 160.6 ± 10.9 |                      |                 |
| Lactate (mmol/L)      | 10.0 ± 3.1    |                      |                 |
| HR\textsubscript{rest}/HR\textsubscript{max} (%) | 198.6 ± 0.5  | 98.2 ± 5.2            |                 |

Legend: BP\textsubscript{s} – Systolic blood pressure; BP\textsubscript{d} – Diastolic blood pressure; HR\textsubscript{rest} – Heart rate in rest; Step tests – Heart rate at the end of step test; Step\textsubscript{a} – Heart rate at the first minute of recovery after step test; PWC\textsubscript{170} – Physical working capacity in heart rate 170 beats per minute; rPWC\textsubscript{170} – PWC\textsubscript{170} relative to body mass; Ve – Pulmonary ventilation; HR\textsubscript{max} – Maximal heart rate; HR\textsubscript{thr} – Heart rate at anaerobic threshold; HR\textsubscript{max,rest} – 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\textsubscript{170} was associated significantly with VO\textsubscript{2max} in absolute values (\( r = 0.65, p = 0.04$), but not with VO\textsubscript{2max} in relative to body mass values (\( r = 0.44, p = 0.20$). The corresponding relationship between rPWC\textsubscript{170} and VO\textsubscript{2max} were \( r = 0.39 (p = 0.27)$ and \( r = 0.60 (p = 0.06)$. Heart rate at the end of the step test was non-significantly related to VO\textsubscript{2max} 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 submaximal CRP indices during the second trial. This improvement was either statistically significant (PWC\textsubscript{170} test) or non-significant (step test). Difficulty in pedalling 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 [18]. 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 VO\textsubscript{2max} were also examined. ICC reached such levels in all submaximal indices, which grounded their reliability regarding desirable levels (> 0.61) [2,3]. Higher scores of ICC were observed in absolute and relative PWC\textsubscript{170} than in step test, suggesting PWC\textsubscript{170} to be more reliable than step test. Correlation between these measures and VO\textsubscript{2max} 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) [16]. Similar association between PWC\textsubscript{170} and VO\textsubscript{2max}, estimated by graded exercise test in treadmill, was observed in non-Caucasian female children (\( r = 0.54, n.s.; N = 8, aged 12 years, VO\textsubscript{peak} 38.5 ± 4.4 mL/min/kg, PWC\textsubscript{170} 1.35 ± 0.42 W/kg\) [18], and higher in Caucasian female adolescents (\( r = 0.84, p < 0.05; N = 18, aged 15.4 ± 0.7 years, VO\textsubscript{max} 42.6 ± 5.8 mL/min/kg, PWC\textsubscript{170} 1.86 ± 0.39 W/kg\) [4].

PWC\textsubscript{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 [28]. CRP was inversely associated with BMI, it was lower in children...
and adolescents with higher BMI [1,8,9,14], and it was in close relationship with the parameters consisting the paediatric metabolic syndrome [7]. Increased risk for cardiovascular disease was found among adolescents with low CRP [15]. Children with chronic diseases had lower CRP than healthy controls [17]. Regarding the prevalence of inactivity [23] and obesity [21,22], particular levels of physical activity should be attained in order to have healthy CRP [19]. Therefore, the development of submaximal 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 [20] and the response to exercise intervention is influenced partially (approximately 50%) by heredity [6], the effectiveness of an exercise intervention should be monitored periodically, where submaximal 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, [4]; n = 9, aged 12 years, [18]). It could be partially attributed to the inherent limitations of laboratory exercise testing, especially in child and adolescent populations.

In summary, the association with VO₂max and the repeatability of submaximal measures of cardiorespiratory power were examined. Both the PWC₁₇₀ and YMCA step test proved to be valid and reliable in active female adolescents. Thus, their wide employment in cardiorespiratory power screening was encouraged. Because these CRP measures depended on heart rate, familiarization with testing procedures should be emphasized to minimize elevation of heart rate due to anxiety. However, these findings should be viewed with some caution until they are confirmed in larger samples.

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