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Original Article

Is the SPARTACUS 15-15 test an accurate proxy for the assessment and tracking of maximal aerobic capacities in adolescents with obesity?

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Abstract. [Purpose] While there is a need for reliable field tests for the evaluation of physical fitness in pediatric obesity, the present work i) evaluates the validity of the Spartacus 15-15 test in indirectly assessing maximal aerobic capacity in adolescents with obesity and ii) evaluates its sensibility to weight loss. [Participants and Methods] Fifty-five 11–16 year-old adolescents with obesity (Tanner 3–4) were enrolled in a 12-week weight-management intervention. Maximal Aerobic fitness (VO_{2peak} test + Spartacus test) and body composition (Dual X-ray absorptiometry) were assessed at baseline and after 12 weeks. [Results] Moderate correlations were found at baseline between VO_{2peak} ($2,231.90 \pm 465.6$ mL/min) and Spartacus stage (6.83 ± 1.8 stage, $r=0.52$; $p \leq 0.05$), speed (12.85 ± 1.8 km/h, $r=0.52$; $p \leq 0.05$) and time (20.6 ± 5.4 min; $r=0.50$; $p \leq 0.05$). The intervention favored significant improvements for VO_{2peak} , Spartacus Rate of Perceived Exertion final stage, maximal speed and time. Change over time in VO_{2peak} and Spartacus variables were not correlated. [Conclusion] The Spartacus test can be used as a proxy for VO_{2peak} at baseline and can be used to estimate VO_{2peak} using the proposed equation. The Spartacus 15-15 test might be a better indicator for changes in functional capacity than an indicator of VO_{2peak} changes in youth with obesity.

Key words: Aerobic fitness, Obese adolescents, Field test

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INTRODUCTION

The alarming prevalence of overweight and obesity among children and adolescents is associated with early psychological, metabolic and functional complications¹⁻⁴. Effective weight management interventions, which employ reliable methods for evaluating health outcomes, are of great importance for the prevention of such co-morbidity and monitoring change over time.

Reliable evaluation methods are particularly necessary for measuring and monitoring change in outcomes related to an individual's physical fitness. While laboratory-based tests are considered as gold standards, access is often limited and testing too costly. This is particularly true when it comes to aerobic fitness where maximal incremental cycling or running tests require direct measurements of oxygen uptake and the supervision of a specialized healthcare staff.

Although indirect, maximal, progressive and continuous field tests are in use, their accuracy remains uncertain, in youth with obesity. Among them, the adapted 20-meter shuttle run test (20-SRT)⁵ and the continuous multi-stage track test (MSTT)⁶ are often used. Although these provide satisfactory⁷ and reproducible⁸ tests among lean children and adolescents, their reliability in youth with obesity is questionable⁹. The MSTT consists of a progressive and continuous test, which oftentimes is prematurely stopped in youth with obesity due to a premature and exacerbated fatigue elicited by the back and forth running. Early stoppage may potentially yield inaccurate estimates of maximal aerobic capacity since youth with obesity often prefer intermittent short-term exercise versus longer continuous exercise regardless of intensity¹⁰. Similarly, the 20-SRT is composed of uninterrupted runs requiring sudden changes in direction which generate high energy costs and musculoskeletal pain and discomfort; all of which lead to premature halting of the test in children with obesity¹¹. The impact on musculoskeletal comfort is of particular importance since musculoskeletal and functional limitations are proposed as a main limiting factor during the assessment of aerobic fitness in children and adolescents with overweight and obesity¹².

The Spartacus 15-15 field test was developed as an intermittent maximal running field test alternating running and rest periods¹³. According to Rey and collaborators, a 20% higher mean maximal speed is observed using the Spartacus compared to the 20-MSTT in adolescents with obesity despite similar maximal heart and perceived exertion rates¹⁴. Our research group recently showed that the Spartacus 15-15 test was highly reproducible among adolescents with obesity and that higher VO_{2peak} and HR_{peak} were obtained using this test compared with other progressive, continuous and maximal test¹⁰. Although the Spartacus test is a reliable method for assessing maximal aerobic capacity among youth with obesity, it has never been compared with a direct laboratory-based measurement of VO_{2peak} and it remains unknown whether results obtained using this test are sensible to weight loss. Indeed, while many studies use the above-mentioned indirect field tests when questioning the effect of weight loss interventions on the physical fitness of adolescents with obesity, their validity and reliability rest on cross-sectional studies, and we did not find any work that investigate their sensitivity to weight loss compared with direct measures such as VO_{2max} .

The first aim of the present study was to test the validity of the Spartacus as an indirect test for assessing maximal aerobic capacities compared with a direct laboratory-based measurement of VO_{2peak} and, secondly, to investigate its sensibility to weight loss in adolescents with obesity. We hypothesize that the Spartacus is a reliable proxy to estimate VO_{2peak} in adolescents with obesity and that this intermittent field test shows a significant sensibility to weight loss in this population.

PARTICIPANTS AND METHODS

Patients attending a specialized pediatric clinic (Pediatric Obesity Department of Romagnat and Tzanou, La Bourboule, France), were eligible to participate in this study. Patients were eligible if they had a Body Mass Index (BMI) above the 90th percentile according to the international reference values¹⁵, were free of any physical contraindications (i.e. recent fracture, articulation issues, etc.) and did not use any medication that could interfere with the principal outcomes of the study. The adolescents and their legal representatives received information sheets and gave their written consent for participation as requested by the ethical authorities (Committee for Human Protection: CPP Sud Est VI, Clinical Trial: NCT02482220).

Following an initial cardiac test and a medical screen by a pediatrician to ensure the ability of the adolescents to complete the protocol, anthropometric measurements were performed, body composition assessed by dual-energy X-ray absorptiometry (DXA, QDR 4500 Hologic), their maximal aerobic fitness (VO_{2peak}) evaluated and they were asked to perform a Spartacus run test. Participants were then enrolled in a 3-month inpatient multidisciplinary intervention designed to induce weight-loss and all measurements were repeated after 12 weeks (T1).

A digital scale (SECA, les Mureaux, France) was used to measure body mass to the nearest 0.1 kg, and height to the nearest 0.5 cm (SECA, les Mureaux, France). Body Mass Index (BMI) was calculated as body mass (kg) divided by height squared (m^2). Waist circumference was measured at the level midway between the last rib and the upper iliac crest. Body composition (Fat Mass percentage (FM%) and Fat-Free Mass (kg)) was assessed using Dual X-ray absorptiometry (DXA, QDR 4500A scanner, Hologic, Waltham, MA, USA).

Each VO_{2peak} was completed under similar conditions at the same time of the day. VO_{2peak} was measured during a graded exhaustive cycling test¹⁶ that was performed at least one week prior to the Spartacus test, by a specialized medical investigator from the Department of Sports Medicine, Functional and Respiratory Rehabilitation (Clermont-Ferrand University Hospital). The initial power was set at 30 W for 3 min and followed by 15 W increments every 1.5 min. Adolescents were

strongly encouraged by experimenters throughout the test to perform a maximum effort. Criteria for reaching VO_{2peak} were subjective exhaustion with heart rate above $195 \text{ beats} \cdot \text{min}^{-1}$ and/or Respiratory Exchange Ratio (RER, VCO_2/VO_2) above 1.02 and/or a plateau of VO_2 . An electromagnetically-braked cycle ergometer (Ergoline, Bitz, Germany) was used to perform the test. VO_2 and VCO_2 were measured breath-by-breath through a mask connected to O_2 and CO_2 analyzers (Oxycon Pro-Delta, Jaeger, Hoechberg, Germany). Calibration of gas analyzers was performed with commercial gases of known concentration. Ventilatory parameters were averaged every 30 s. ECG was monitored for the duration of the test.

Each Spartacus test was completed under similar conditions at the same time of the day. As previously described by Rey et al., a rectangle of 750 meters ($75 \times 10 \text{ m}$)² was created with different marks set at regular intervals, which represent the different speeds (from 7 to 18 km/h)¹⁴. Each stage lasts three minutes whereby the first stage is set at 7 km/h and each following stage increasing by 1 km/h every three minutes. During the three minutes (for each stage/ speed), participants had 15 sec to reach the corresponding mark and then 15 sec of rest. As such, each stage lasts three minutes and is composed of 90 sec of running and 90 sec of rest. As soon as the participant was not able to complete a whole stage, the test was interrupted and the last completed stage recorded. Participants ran in groups of no more than 5. Figure 1 illustrates the Spartacus protocol. Heart rate was continuously monitored during the test (Polar Electro Inc. RS800CX) and the adolescents' rate of perceived exertion (RPE) was also evaluated at the end of different stage using an adapted version of the Borg Scale (rated from 0 to 10 with 10 representing a maximal effort that cannot be sustained and the need to interrupt the test).

The fifty-five adolescents were enrolled in a 12-week weight management program combining dietary education and physical activity, at the Pediatric Obesity clinical center (Centre Medical Infantile Romagnat & Tzanou, France). Every week, adolescents completed two 60-minute exercise sessions combining resistance and aerobic exercises as well as a third session composed of combined recreative activities and sport games (i.e. ball and racquet games or recreational activities such as trekking or snowshoeing). The adolescents also attended nutritional education classes twice a month led by a dietician and received psychological support through individualized consultation with a professional once a month. During the intervention, the adolescents were submitted to a normo-caloric diet based on their age and gender recommendations¹⁷.

The statistical analyses were carried out using the statistical software Stata (version 13, StataCorp, College Station, USA). All statistical tests were conducted for a two-sided type I error at 0.05. Continuous variables were described as mean and standard-deviation or median and interquartile range, according to statistical distribution (assumption of normality studied using Shapiro-Wilk test). Paired comparisons were performed using paired Student t-test, or Wilcoxon test when assumptions of t-test were not met. The results were expressed as paired Hedges's effect-sizes. Furthermore, the relationships between quantitative parameters were studied using correlation coefficients (Pearson or Spearman according to the statistical distribution), applying a Sidak's correction to take into account multiple comparisons. Then, to estimate VO_{2peak} , an equation has been proposed by multiple linear regression model. The covariates were determined according to univariate results and clinical relevance: age, gender and BMI. The normality of residuals was studied using the Shapiro-Wilk test and a logarithmic transformation of dependent variable was proposed to achieve the normality. A particular attention was paid on study of multicollinearity. The results were expressed as regression coefficients and 95% confidence intervals.

RESULTS

The whole sample was aged 13.1 ± 1.2 years with a body mass of $92.16 \pm 14.1 \text{ kg}$ and a mean BMI of $35.06 \pm 4.3 \text{ kg/m}^2$. The adolescents mean fat mass percentage and fat free mass were $37.97 \pm 3.9\%$ and $55.41 \pm 9.0 \text{ kg}$ respectively.

Baseline (T_0), VO_{2peak} ($2,231.90 \pm 465.6 \text{ mL/min}$) was significantly correlated with the T_0 last Spartacus stage (6.83 ± 1.8

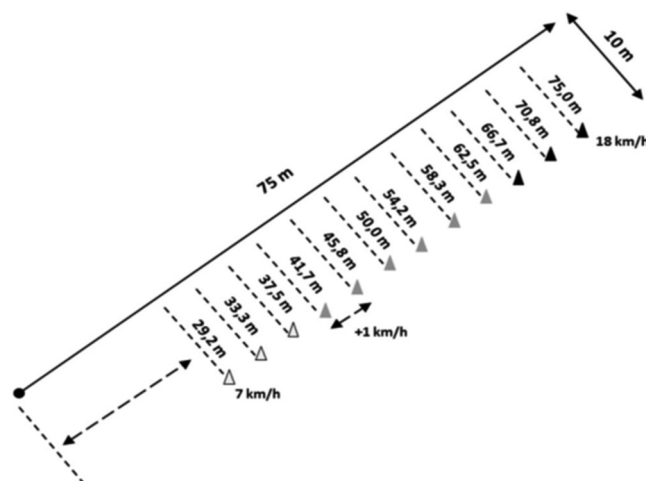


Fig. 1. The Spartacus protocol (adapted from Rey et al., 2013)

stage; $r=0.52$; $p\leq 0.05$); distance (53.28 ± 7.4 m; $r=0.52$; $p\leq 0.05$), speed (12.85 ± 1.8 km/h; $r=0.52$; $p\leq 0.05$) and time (20.6 ± 5.4 min; $r=0.50$; $p\leq 0.05$).

An equation can be proposed to estimate VO_{2peak} based on the performance obtained during the Spartacus test (Table 1 details the results of the multivariate regression performed to compute this equation). This equation integrates “age”, “gender”, “BMI” and “last SPARTACUS stage validated” ($r=0.68$):

VO_{2peak} estimation equations:

Girl: Last stage * 153.4433 + BMI * 58.64534 + age * -2.701522 - 921.2878

Boy: Last stage * 153.4433 + 320.1583 + BMI * 58.64534 + age * -2.701522 - 921.2878

As described by Table 2, body mass was significantly decreased (ES: 0.38 [-0.2 -0.96]; $p\leq 0.001$), as well as BMI (ES: 0.7 [0.11-1.3]; $p\leq 0.001$) and fat mass (ES: 0.97 [0.36 -1.58]; $p\leq 0.001$), while fat free mass did not change significantly.

Table 3 presents the VO_{2peak} and Spartacus test results between baseline and T1. VO_{2peak} was significantly improved by the end of the intervention (ES: -0.43 [-1.01-0.16]; $p<0.05$). The Spartacus RPE (ES: -2.29 [-0.89 -0.31]; $p\leq 0.05$), last completed stage (-0.84 [-1.45 to -0.23]; $p\leq 0.001$), maximal speed (-0.81 [-0.41 to -0.21]), total times (-0.79 [-1.39 to

Table 1. Results from the multivariate regression used for the elaboration of the equation

	Coefficient	SD	95%CI	p
Last stage	153.4	30.7	[91.4, 215.4]	***
BMI (kg/m ²)	58.6	13.3	[31.6, 85.6]	***
Age (years)	-2.7	46.8	[-97.1, 91.7]	0.954
Gender ^a	320.1	97.1	[124.2, 516.0]	***
Constant variable	-921.2	600.4	[-2131.3, 288.7]	0.132

SD: Standard Deviation; CI: Confidence Interval; *** $p<0.001$; ^a when gender is boy.

Table 2. Body composition and comparison between T0 and T1

	T0	T1	ES	p
Body mass (kg)	92.16 ± 14.1	85.0 ± 15.7	0.38 [-0.2, 0.96]	***
BMI (kg/m ²)	35.06 ± 4.3	32.1 ± 4.3	0.7 [0.11, 1.3]	***
Fat mass (%)	37.97 ± 3.9	32.1 ± 4.3	0.97 [0.36, 1.58]	***
Fat free mass (kg)	55.41 ± 9.0	54.3 ± 10.0	-0.006 [0.56, 0.57]	

T0: baseline; T1: end of the intervention; BMI: Body Mass index; ES: Effect Size; * $p<0.05$; ** $p<0.01$.

Table 3. Results and comparison between T0 and T1 for the VO_{2peak} and Spartacus test

	T0	T1	ES [95%CI]	p
Laboratory test				
VO_{2peak} (ml/min)	2,231.9 ± 465.6	2,457.0 ± 396.2	-0.43 [-1.01, 0.16]	*
HR _{peak} (bpm)	185.3 ± 8.5	183.5 ± 15.3	0.25 [-0.32, 0.82]	
Spartacus 15-15 test				
RPE _{end} (scale 1-10)	8.1 ± 1.7	6.4 ± 2.4	-2.29 [-0.89, 0.31]	*
HR _{peak} (bpm)	193.8 ± 9.5	191.1 ± 10.2		
Last stage	6.8 ± 1.8	8.0 ± 2.6	-0.84 [-1.45, -0.23]	***
Maximal distance (m)	53.3 ± 7.4	57.7 ± 11.6	-0.74 [-0.12, 1.35]	**
Maximal speed (km/h)	12.9 ± 1.8	14.1 ± 2.5	-0.81 [-0.41, -0.21]	***
Total time (min)	20.6 ± 5.4	24.2 ± 7.5	-0.79 [-1.39, -1.19]	***
RPE last stage T0	8.2 ± 1.6	3.8 ± 2.1	0.88 [0.30, 1.45]	***
HR last stage T0	176.4 ± 12.5	186.4 ± 36.2	-1.67 [-0.73, 0.39]	***

T0: baseline; T1: end of the intervention; HR: Heart Rate; RPE: Rate of Perceived Exertion; ES: Effect Size; * $p<0.05$; ** $p<0.01$; *** $p<0.001$.

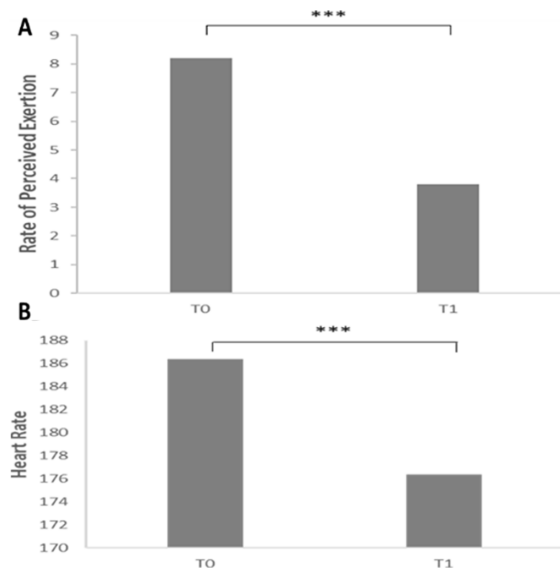


Fig. 2. Changes of the adolescents Rate of Perceived Exertion (A) and Peak of Heart Rate (B) recorded at the end of the last stage completed in the Spartacus test.
T0: baseline; T1: end of the intervention; *** $p < 0.001$.

-1.19]) ($p \leq 0.001$) and maximal distance (-0.74 [1.35 to -0.12]; $p \leq 0.01$) were significantly improved. Maximal heart rate did not change between baseline and T1 during both the VO_{2peak} and Spartacus tests.

After the intervention (T1), the adolescents' heart rate and rate of perceived exertion (RPE) recorded at the end of the last stage completed at T0 were both significantly improved ($p < 0.001$) as illustrated by Fig. 2.

There was no significant correlation between the absolute VO_{2peak} and the Spartacus results at T1 and the VO_{2peak} and Spartacus results variations (using deltas) were not correlated. None of the Spartacus outcome changes between T0 and T1 was correlated with body weight, BMI, fat mass % and fat free mass changes. The VO_{2peak} variation was not correlated with body weight and FM% changes but significantly correlated with fat free mass ($r = 0.48$; $p < 0.05$) and BMI ($r = 0.49$; $p < 0.05$) variations.

DISCUSSION

While it exists many field tests to evaluate aerobic fitness among children and adolescents, their accuracy in youth with overweight or obesity remains debated. The first aim of the present work was to test the validity of the Spartacus as an indirect test assessing maximal aerobic capacities compared with a direct measurement of VO_{2peak} and, secondarily, to investigate its sensibility to weight loss in adolescents with obesity.

The Spartacus test, as an intermittent progressive and maximal 15-15 test elaborated to indirectly evaluate children and adolescents' aerobic capacities has been previously compared with usually used field tests such as the 20-MSRT or the Leger-Boucher continuous test and has been found to provide satisfactory results in both lean adolescents and youth with obesity^{14, 18}. More recently, Thivel and collaborators suggested that this Spartacus 15-15 test could be more appropriate than the other classically used continuous and progressive field ones for assessing functional capacities in adolescents with obesity¹⁹. Although the authors also found the Spartacus 15-15 test to be highly reproducible, they pointed out the need for direct comparisons with laboratory based VO_{2peak} measurements¹⁹. The present work is to our knowledge the first to directly compare the Spartacus performances to a direct laboratory-based measure of maximal aerobic fitness in adolescents with obesity. According to our results, the Spartacus test provides an accurate estimation of VO_{2peak} in 11 to 16 years old adolescents with obesity. Indeed, our analyses show significant correlations between the different Spartacus outcomes (distance, speed, final stage) and the measured VO_{2peak} . Importantly, although these correlations are significant and clinically relevant, they remain moderate, suggesting that the Spartacus test might not be an exact direct proxy for VO_{2peak} but, as previously suggested, might provide a great estimation of the adolescents' aerobic and functional capacities¹⁹. This is reinforced by the fact that these significant correlations have been obtained at baseline only (despite improvement of both VO_{2peak} and Spartacus performances as discussed below). Based on these results, we also propose here the use of an equation integrating the adolescents' individual characteristics (age, gender, BMI) and Spartacus performances (last completed stage) to better estimate baseline VO_{2peak} based on the results obtained during the field test. Since laboratory-based evaluations are rarely available to practitioners and clinicians who rely on indirect field test to assess their patients' capacities²⁰ and based on the

practical feasibility of the Spartacus test, such an equation can help these practitioners elaborating and calibrating their interventions (individualizing the exercise intensities and their progression for instance). Although some previously published studies proposed equations based on individual characteristics such as body weight and body composition, anthropometric measurements, gender or age to estimate VO_{2peak} among children and adolescents^{21–23}) we found only few studies that proposed an equation integrating performances issued from a field test^{5, 23, 24}).

Although these first results point out a moderate correlation between the performances obtained during the Spartacus test and a direct measure of VO_{2peak} in adolescents with obesity, we also questioned here whether this field test was sensible to weight loss and whether the improvements observed in response to a multidisciplinary intervention were associated with anthropometric, body composition and VO_{2peak} changes. Our results show significant correlations between the variations of weight, BMI, fat mass (%) and the improvement of the performances obtained by the adolescents by the end of the intervention, which joins up with previously published studies in the field²⁴). However, while both the direct measure of VO_{2peak} and the Spartacus performances (last completed stage, maximal covered distance, HRmax, maximal speed, RPEend and total duration) showed significant improvements in response to a 3-month intervention; we missed to find any correlation between these changes. Indeed, based on our statistical analysis, the moderate correlations observed between VO_{2peak} and the Spartacus performances at baseline did not exist anymore at T1, and the progression deltas for VO_{2peak} and the Spartacus results were not found correlated. Importantly, our concordance analysis also missed to reveal any relationship between these two tests between T0 and T1. Although many studies have used field tests to assess aerobic fitness and its response to weight loss programs in children and adolescents with obesity^{25, 26}) we missed to find any already existing analysis of the sensitivity of these tests as potential proxies for VO_2 changes after weight loss in youth with obesity. This sounds of particular importance since most of researchers and practitioners commonly associate these results as indirect measures for aerobic capacities. Even though the Spartacus (certainly such as other equivalent field tests whose sensibility to weight loss remains to be determined) might not be a great indirect tool to estimate VO_{2peak} changes, our results clearly show significant improvements of its performances in our sample, highlighting its feasibility and potential reliability to assess the adolescents' functional progression after such a multidisciplinary program. These improvements are illustrated by the significant progression of all the results obtained thanks to the Spartacus test at T1 compare with baseline and also interestingly by the significantly lower rate of perceived exertion obtained at T1 after the completion of the final stage completed at baseline.

The present results have to be considered in light of some limitations. Indeed, the number of participants is rather low, with an unequal girl/boy distribution. Moreover, our panel of participants included pre and post-puberty adolescents aged of 11 to 16 years, which could have influenced the responses to both tests due to the metabolic changes occurring during puberty that influence aerobic capacities²⁷). Mainly, this work lacks from a direct evaluation of the adolescents oxygen consumption during the Spartacus test. Indeed, the use of a portable calorimeter to assess VO_2 would have provided important results to enrich our comparison with the laboratory measurement of VO_{2peak} . However, this remained difficult here for practical reasons.

While field tests are mainly used by practitioners, the Spartacus progressive and intermittent maximal 15-15 test proposes a great alternative to laboratory-based evaluation that remains hardly accessible. The present preliminary results add to the actual literature that this Spartacus can be used as an interesting proxy for VO_{2peak} at baseline and proposes an equation based on its performances to estimate VO_{2peak} in adolescents with obesity. Such equations are of particular importance since few practitioners have access to direct measurements of aerobic capacities (such as VO_{2peak}) that are needed to better calibrate their interventions. It seems however that the improvements observed during a Spartacus test in response to a 3-month multidisciplinary weight loss program cannot be used as proxies for VO_{2peak} changes in this population but as potential indicators of the adolescents' overall functional capacity improvements.

Conflict of interest

The authors report no conflicts of interest.

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