Cardiorespiratory Fitness Evaluation in Obese Youth

Julien Aucouturier[1] and David Thivel[2]

[1] Julien Aucouturier is assistant professor at the Faculty of Sports Sciences and Physical Education, at Lille 2 University (France).

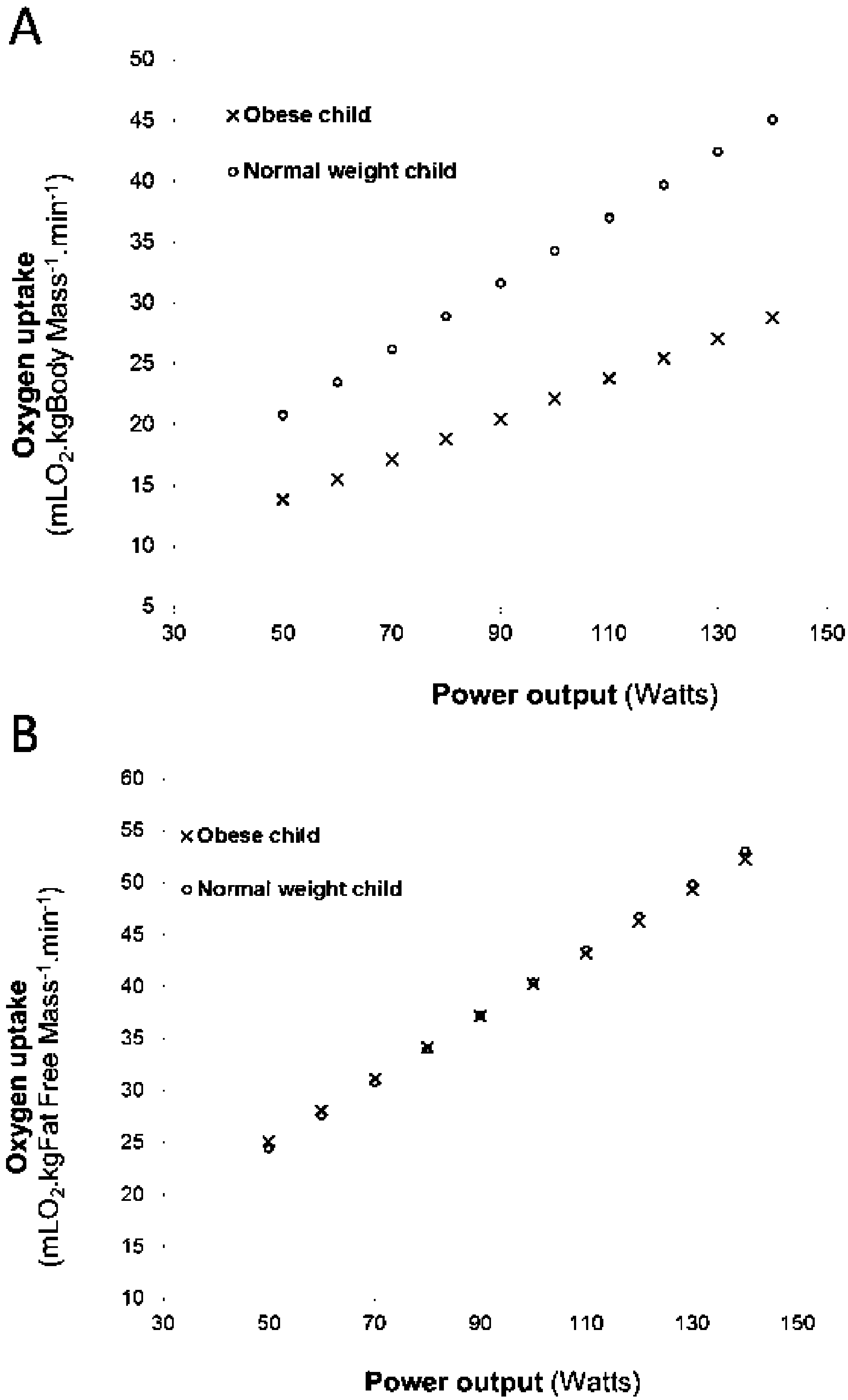
[2] David Thivel is Assistant Professor at the Faculty of Sports Sciences at Blaise Pascal University (Clermont-Ferrand, France).

Cardiorespiratory fitness in obese children and adolescents

Obese children and adolescents usually have lower overall physical abilities and especially lower cardiorespiratory fitness (CRF) when compared to their normal-weight peers. This is mainly because of the increased effort required to move their larger body mass and carry an excessive amount of body fat[1]. It is only among extremely obese children that the lower CRF can partly result from impaired lung function, with decreased expiratory reserve volume and functional residual capacities due to their lower chest wall and lung compliance[2-5]. He and al. did not observe any difference of pulmonary functions between lean and obese children, despite a higher prevalence of respiratory symptoms that may occasionally impair cardiorespiratory fitness in obese youth [6]. Although lower cardiorespiratory performances are observed in obese children and adolescents compared to those of lean children and adolescents when adjusted to body mass, absolute performances are similar or higher, and these differences disappear when performances are adjusted to fat free mass, suggesting that muscle maximal oxidative ability is not impaired with obesity in youth[7, 8]. As an example, Lazzer et al. reported a maximal oxygen uptake (VO_{2max}) approximately 27% higher in 12-16 year old obese youth when expressed in absolute terms ($L.min^{-1}$), but when VO_2max was adjusted to Fat-Free Mass there was no difference between the obese adolescents and their normal weight controls as illustrated by the Figure 1[9]. Using an incremental treadmill test conducted to exhaustion and the measurement of VO_2max, Watanabe et al. observed an inverse and significant relation between 12-15 year old obese adolescents' CRF and their body fat mass[7]. CRF results are similar when VO_2max cannot be directly assessed and indirect methods are used to assess CRF (Queen's college step test)[10]. Excessive body fat is also thought to contribute to the exercise intolerance and low CRF in obese youth[7]. Some studies suggest different effects of obesity in girls and boys, as Mota et al. did not observe any CRF difference between lean, overweight or obese 8 year old boys, whereas overweight and obese girls were more likely to be unfit compared to lean girls[11]. This is in accordance with previous findings from a longitudinal study showing that CRF among girls but not boys was significantly associated with the incidence of overweight and obesity[12].

A

B



Oxygen uptake
(mLO2.kgBody Mass-1.min-1)
50
45
40
35
30
25
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15
10
5
× Obese child
o Normal weight child
30
50
70
90
110
130
150
Power output (Watts)
Oxygen uptake
(mLO2.kgFat Free Mass-1.min-1)
60
55
50
45
40
35
30
25
20
15
10
× Obese child
o Normal weight child
30
50
70
90
110
130
150
Power output (Watts)

Figure 1. *Illustration of the VO_2 differences between lean and obese youth depending on its expression during an incremental exercise test (relative to Body Mass (A) or Fat Free Mass (B).*

Although exercise training represent the best method to improve CRF in obese youth, their initial low fitness level is a barrier to their engagement in regular physical activity, contributing to the poor compliance usually observed in physical activity interventions[13]. An important clinical challenge to track the changes in physical fitness with these interventions is to properly assess CRF in obese youth by using validated and accurate tests.

How to measure CRF in pediatric obesity?

Maximal oxygen uptake (VO_{2max}): the "Gold Standard"

Laboratory tests to assess cardiorespiratory fitness either measure or predict oxygen uptake (VO_{2max}) and are accepted as reference methods[14-17]. Basically, VO_2max is assessed during a cycling or running graded exhaustive test with increasing workload (in Watt) when performed on a cycle ergometer or speed and/or slope when performed on a treadmill. Whether it is on a cycle ergometer or a treadmill, the stage duration at each workload or speed ranges between 1 to 3 minutes of duration. In children and adolescents, the criteria for achievement of VO_{2max} are subjective exhaustion, heart rate above 195 beats.min-1 and/or Respiratory Exchange Ratio (RER, VCO_2/VO_2) above 1.02 and/or a plateau of VO_2[18]. Although this method is widely used the completion of maximal test requires strong encouragement from the investigation or medical team and remains difficult to perform in obese subjects. Obese children and adolescents specifically have been shown to express a significantly higher rate of perceived exertion during incremental test compared to their normal-weight peers 19, with pain and fatigue considered as the main causes. Children who rarely engage in physical activity of high intensity, often fail to reach the required VO_{2max} criteria during a maximal CRF test, and if the aforementioned criteria are not met, the maximal oxygen uptake measured is termed VO_{2peak} rather than VO_{2max}[20]. VO_{2peak} represents the highest value of oxygen consumed by participants in a maximal protocol but with less stringent criteria than VO_{2max}. As an example, Breithaupt et al. reported that only 18 out of 62 obese children who performed a maximal CRF test were able to achieve VO_{2max} based on the criteria presented above [21].

In addition to the measurement of VO_{2max}, two ventilatory thresholds (VT1 and VT2) can be determined during incremental test and are each characterized by a disproportionate increase in minute ventilation (VE) relative to the increase in VO_2. Also VT1 and VT2 are considered as good physiological indicators of cardiorespiratory endurance, they are difficult to determine accurately in obese children and adolescents due to frequently erratic breathing. Some authors indicate that the thresholds are almost undetectable in up to 20% of children and adolescents [22, 23]. Despite these limitations, VT determination can be used for exercise prescription. For example, training below VT1 will represent a moderate intensity of exercise that will favor fat oxidation [24], training alternating moderate and high intensities (between VT1 and VT2) has been shown to reduce cardiovascular risk factors[25] and exercising at the VT2 can reduce post-exercise energy consumption[26].

Maximal laboratory tests with gas exchange measurement may represent the most accurate method to asses CRF, but these tests are often expensive and not accessible to all obese youth. Submaximal tests have been therefore been developed[27] for and validated in the general pediatric population, and are now applied to obese youth.

Submaximal tests: from the laboratory to the field setting

When using validated tests, submaximal exercise testing offers a valuable and reliable alternative to estimate VO_{2max}. Submaximal measures do not require the participants to exercise until exhaustion and may thus overcome some of the limitations of maximal testing and are better tolerated by patients experiencing physical limitation, important fatigue and pain while exercising [17]. Basically, extrapolations of VO_{2max} or maximal power output are performed from the theoretical maximal heart rate (HR), and the linear relationship between power output (or VO_2) and heart rate measured during at least two bouts of exercise performed at two different submaximal intensities of exercise[28]. Estimation of CRF can also be done using other predictive variables such as HR recovery during step tests[29, 30] or validated predictive equations with parameters such as age, gender, body weight or rest heart rate among others [31-33].

Recently, Breithaupt et al. proposed a new submaximal protocol adapted to obese youth (The HALO protocol: Healthy Active Living and Obesity research group Protocol) that they compared with a direct progressive maximal test to exhaustion in 21 obese adolescents[34]. The test consists in a walking test at constant speed (brisk but comfortable) during 4-min stages to ensure that steady state of VO_2 and HR is reached. After a 4-min warm-up, the incline of the treadmill is increased by 3% over each subsequent stage. The test ends when: i) the participant reaches 85% of his maximal estimated HR; ii) he completes 20 minutes of exercise; iii) he indicates that he can no longer continue. Then VO_{2peak} is predicted by extrapolating the HR-VO_2 linear relationship to age-predicted HRmax. While only 29% of their sample reaches a VO_2 plateau during the maximal test, all the participants ended the HALO protocol and expressed lower RPE. According to their results, the HALO submaximal protocol provides an accurate and valid method to estimate VO_{2peak} compared with a classical maximal test. Furthermore, this test results in better estimates of VO_{2peak} compared with previously validated submaximal estimations in obese youth[34].

A shorter submaximal protocol has also been validated in obese adolescents against a laboratory-bases maximal VO2max measure. Nemeth et al. asked 113 obese 12 year old boys and girls to complete a 4-minute treadmill exercise[33]. After a 4-minute warm-up at a self-selected confortable walking speed (treadmill grade = 0%); the participants were asked to maintain this speed for 4 minutes while the treadmill grade increased to 5%. Heart rate was recorded at rest and at the end of the 4 minutes as well as the self-selected speed. Based on these two variables, the authors proposed an equation that also included sex, weight (kg) and height (cm) to estimate VO_{2max}. These simple methods requiring only HR measurement accurately predict VO_{2max} in overweight and obese children and adolescents[33] and offers then practitioners feasible and simple methods to assess cardiorespiratory fitness.

Several inexpensive, easy to implement and reproducible field-methods initially validated in non-obese youth are commonly used obese youth 17, 35-37. The two main field tests used among pediatric obese populations are the Six-Minute Walk Test (6MWT) and the 20-Meter Shuttle Run Test (20MST).

The 6-minute walk test is an accurate and convenient method to assess CRF at submaximal intensity in children[38] and has been shown to better reflect daily living activities than any other functional walk test[39]. The recently established reference values have facilitated the use of the 6MWT and allow determining whether a child has a good or a poor CRF[40-44]. Not surprisingly, several studies have shown lower distances completed during the 6MWT in obese compared to lean children and adolescents[45, 46]. Elloumi et al. confirmed the validity of the 6MWT in obese adolescents by comparison with a validated incremental submaximal protocol with gas exchange measurements[47]. The 6MWT has also been shown to be sensitive to changes in physical fitness of obese adolescents following a 2-month physical activity[47, 48]. The 6MWT has also been used to estimate the maximal fat oxidation point (Fatmax or lipoxmax), when gas exchange measurement – with the VO_2 and VCO_2 data used to calculate the rate of fat oxidation – is not available (using the distance performed during the test as a central values in a predictive equation)[49].

The 20-meter shuttle run test (20MST) developed by Leger et al. is among the most used field tests to assess cardiorespiratory fitness in youth [50]. During this test, children are instructed to run for as long as possible between two lines drawn 20 meters apart at an increasing speed imposed by a recording emitting tones at appropriate intervals. The test starts at 8 km/h and increases by 0.5 km/h every minute. The test ends when the participant is not able anymore to complete a whole stage. Castro-Pineiro et al. showed that overweight and obese children performed less well than lean ones at this test [51], and this is partly explained by the excessive start speed during the original test (8 km/h). This led to the development of an adapted version of the test, with the use of an incremental shuttle walk test with 15 levels from 1.8 to 10.3 km/h over a 10-meter distance[36]. More recently, an adapted version of the 20MST has been developed in obese children and adolescents [52]. Ten stages have been added at the beginning of the original 20MSRT in order to reduce the starting speed and speed over the duration of the test [52]. Then, the participants are asked to start at 4 km/h (walk speed) with an increment of 0.5 km/h every minute. The original start speed of 8 km/h is reach after the first 10 minutes. The authors reported a strong correlation between the maximum speed obtained and laboratory-assessed peak VO_2 (r=0.81), which indicates the validity of this adapted version of the test in obese youth [52].

Conclusion and recommendations

Cardiorespiratory fitness is impaired in obese children and adolescents, and is among the main reasons for their low engagement into physical activities. There is a double interest in properly assessing CRF in this population. First, CRF is an important clinical parameter for the diagnosis and follow-up of the current and future functional and metabolic health of obese youth. A laboratory-based direct and maximal assessment should thus be encouraged.

Second, from a more practical point of view, CRF is necessary information to obtain when implementing interventions for the treatment of obesity, especially when it is based on physical activity-based programs. Disposing of CRF indicators will help the practitioners and/or educators to properly prescribe physical activities by determining the appropriate exercise intensities and controlling their progression through the intervention. When direct VO_{2max} measurement is not available, submaximal and field testing are reliable alternatives. Thanks to their easy feasibility, these tests can be repeated many times during the program to and bring adaptation to the exercise prescription if necessary.

BOX 1
Cardiorespiratory fitness, or **aerobic capacity**, describes the ability of the body to perform high-intensity activity for a prolonged period without undue physical stress or fatigue. High level of cardiorespiratory fitness enables people to carry out their daily occupational tasks and leisure pursuits more easily and with greater efficiency [53]. **Cardiorespiratory endurance**, or **aerobic fitness,** is the ability of the cardiorespiratory system to supply oxygen to active skeletal muscles during prolonged submaximal exercise and the ability of the skeletal muscles to perform aerobic metabolism [54].

BOX 2
Limiting factors in the evaluation of CRF in obese youth **Pain**. The excess body weight characterizing overweight and obesity is responsible for increase overall and lower limb musculoskeletal pain limiting their engagement in exercise[55]. In a recent review, Smith et al. pointed out the musculoskeletal and osteoarticular dysfunction and pain induced by obesity in youth[56]. Overweight and obese children and adolescents experience decreased joint health and increased dysfunction resulting in more ankle, foot and knee problems than their lean peers[57]. Such physical impairments are limiting factors leading to premature interruption during maximal and submaximal testing. **Respiratory limitations**. Obesity is accompanied by numbers of respiratory complications that limits the adherence of overweight and obese youth to exercise testing and programs. Decreased thoracic compliance, increased airway resistance and breathing at low pulmonary volumes have been identified among others[58-60] and contribute to ventilator constraint 61, increased fatigue of respiratory muscles[62] leading then to dyspnea. Since ventilator response to exercise in youth is excessive relative to the metabolic demand, it increases ventilator constraint in obese children and adolescents[63, 64]. In addition, due to their reduced airways relative to lung size [65] youth with obesity experience increased expiratory flow limitation that limits their compliance to maximal and submaximal exercises[66]. **Rate of Perceived Exertion (RPE).** Although few data are available regarding the real perceived exertion of obese youth during incremental tests, it has been shown that obese children rate their perceived exertion during a CRF test significantly higher than their lean peers[19]. Belanger et al. found that obese adolescents express higher absolute RPE during a maximal incremental test compared with a submaximal one [67]. According to Ward & Bar-Or, the excess body weight and lower physical abilities and capacities induced by obesity increase their perception of exercise difficulties and compose the main limitations to physical activity[68]. This excessive RPE during exercise may lead to premature interruption of the tests and then underestimation of their aerobic capacities.

References

1. Dupuis JM, Vivant JF, Daudet G, Bouvet A, Clement M, Dazord A, et al. [Personal sports training in the management of obese boys aged 12 to 16 years]. Arch Pediatr. 2000; 7: 1185-93.
2. Fung KP, Lau SP, Chow OK, Lee J, Wong TW. Effects of overweight on lung function. Arch Dis Child. 1990; 65: 512-15.
3. Ferretti A, Giampiccolo P, Cavalli A, Milic-Emili J, Tantucci C. Expiratory flow limitation and orthopnea in massively obese subjects. Chest. 2001; 119: 1401-8.
4. Zerah F, Harf A, Perlemuter L, Lorino H, Lorino AM, Atlan G. Effects of obesity on respiratory resistance. Chest. 1993; 103: 1470-6.
5. Ray CS, Sue DY, Bray G, Hansen JE, Wasserman K. Effects of obesity on respiratory function. Am Rev Respir Dis. 1983; 128: 501-6.
6. He QQ, Wong TW, Du L, Jiang ZQ, Qiu H, Gao Y, et al. Respiratory health in overweight and obese Chinese children. Pediatr Pulmonol. 2009; 44: 997-1002.
7. Watanabe K, Nakadomo F, Maeda K. Relationship between body composition and cardiorespiratory fitness in Japanese junior high school boys and girls. Ann Physiol Anthropol. 1994; 13: 167-74.
8. Goran MI. Energy metabolism and obesity. Med Clin North Am. 2000; 84: 347-62.
9. Lazzer S, Boirie Y, Bitar A, Petit I, Meyer M, Vermorel M. Relationship between percentage of VO2max and type of physical activity in obese and non-obese adolescents. J Sports Med Phys Fitness. 2005; 45: 13-9.
10. Chatterjee S, Chatterjee P, Bandyopadhyay A. Validity of Queen’s College Step Test for estimation of maximum oxygen uptake in female students. Indian J Med Res. 2005; 121: 32-5.
11. Mota J, Flores L, Ribeiro JC, Santos MP. Relationship of single measures of cardiorespiratory fitness and obesity in young schoolchildren. Am J Hum Biol. 2006; 18: 335-41.
12. Kim J, Must A, Fitzmaurice GM, Gillman MW, Chomitz V, Kramer E, et al. Relationship of physical fitness to prevalence and incidence of overweight among schoolchildren. Obes Res. 2005; 13: 1246-54.
13. Quinart S, Mougin-Guillaume F, Simon-Rigaud ML, Bertrand AM, Negre V. [Sports counseling for overweight children]. Arch Pediatr. 2010; 17: 894-5.
14. Balke B, Ware R. An experimental study of Air Force personnel. US Armed Forces Med Journal. 1959; 10: 675-88.
15. Bruce RA, Kusumi F, Hosmer D. Maximal oxygen intake and nomographic assessment of functional aerobic impairment in cardiovascular disease. Am Heart J. 1973; 85: 546-62.

16. Patterson JA, Naughton J, Pietras RJ, Gunnar RM. Treadmill exercise in assessment of the functional capacity of patients with cardiac disease. Am J Cardiol. 1972; 30: 757-62.

17. Noonan V, Dean E. Submaximal exercise testing: clinical application and interpretation. Phys Ther. 2000; 80: 782-807.

18. Rowland TW. Developmental Exercise physiology. . Human Kinetics ed edn. Champaign, IL 1996.

19. Marinov B, Kostianev S, Turnovska T. Ventilatory efficiency and rate of perceived exertion in obese and non-obese children performing standardized exercise. Clin Physiol Funct Imaging. 2002; 22: 254-60.

20. Wagner PD. New ideas on limitations to VO2max. Exerc Sport Sci Rev. 2000; 28: 10-4.

21. Breithaupt PG, Colley RC, Adamo KB. Using the oxygen uptake efficiency slope as an indicator of cardiorespiratory fitness in the obese pediatric population. Pediatr Exerc Sci. 2012; 24: 357-68.

22. Washington RL, van Gundy JC, Cohen C, Sondheimer HM, Wolfe RR. Normal aerobic and anaerobic exercise data for North American school-age children. J Pediatr. 1988; 112: 223-33.

23. Owens S, Gutin B. Exercise testing of the child with obesity. Pediatr Cardiol. 1999; 20: 79-83; discussion 84.

24. Lazzer S, Lafortuna C, Busti C, Galli R, Tinozzi T, Agosti F, et al. Fat oxidation rate during and after a low- or high-intensity exercise in severely obese Caucasian adolescents. Eur J Appl Physiol. 2010; 108: 383-91.

25. Tjonna AE, Stolen TO, Bye A, Volden M, Slordahl SA, Odegard R, et al. Aerobic interval training reduces cardiovascular risk factors more than a multitreatment approach in overweight adolescents. Clin Sci (Lond). 2009; 116: 317-26.

26. Thivel D, Isacco L, Montaurier C, Boirie Y, Duche P, Morio B. The 24-h energy intake of obese adolescents is spontaneously reduced after intensive exercise: a randomized controlled trial in calorimetric chambers. PLoS One. 2012; 7: e29840.

27. Cottin F, Lepretre PM, Lopes P, Papelier Y, Medigue C, Billat V. Assessment of ventilatory thresholds from heart rate variability in well-trained subjects during cycling. Int J Sports Med. 2006; 27: 959-67.

28. Astrand I. Aerobic work capacity in men and women with special reference to age. Acta Physiol Scand Suppl. 1960; 49: 1-92.

29. Weller IM, Thomas SG, Corey PN, Cox MH. Selection of a maximal test protocol to validate the Canadian Aerobic Fitness Test. Can J Sport Sci. 1992; 17: 114-9.

30. Weller IM, Thomas SG, Cox MH, Corey PN. A study to validate the Canadian Aerobic Fitness Test. Can J Public Health. 1992; 83: 120-4.

31. Dolgener FA, Hensley LD, Marsh JJ, Fjelstul JK. Validation of the Rockport Fitness Walking Test in college males and females. Res Q Exerc Sport. 1994; 65: 152-8.

32. Ebbeling CB, Ward A, Puleo EM, Widrick J, Rippe JM. Development of a single-stage submaximal treadmill walking test. Med Sci Sports Exerc. 1991; 23: 966-73.

33. Nemeth BA, Carrel AL, Eickhoff J, Clark RR, Peterson SE, Allen DB. Submaximal treadmill test predicts VO2max in overweight children. J Pediatr. 2009; 154: 677-81.

34. Breithaupt P, Adamo KB, Colley RC. The HALO submaximal treadmill protocol to measure cardiorespiratory fitness in obese children and youth: a proof of principle study. Appl Physiol Nutr Metab. 2012; 37: 308-14.

35. Drinkard B, McDuffie J, McCann S, Uwaifo GI, Nicholson J, Yanovski JA. Relationships between walk/run performance and cardiorespiratory fitness in adolescents who are overweight. Phys Ther. 2001; 81: 1889-96.

36. Klijn PH, van der Baan-Slootweg OH, van Stel HF. Aerobic exercise in adolescents with obesity: preliminary evaluation of a modular training program and the modified shuttle test. BMC Pediatr. 2007; 7: 19.

37. Wallman KE, Campbell L. Test-retest reliability of the Aerobic Power Index submaximal exercise test in an obese population. J Sci Med Sport. 2007; 10: 141-6.

38. Nixon PA, Joswiak ML, Fricker FJ. A six-minute walk test for assessing exercise tolerance in severely ill children. J Pediatr. 1996; 129: 362-6.

39. Solway S, Brooks D, Lacasse Y, Thomas S. A qualitative systematic overview of the measurement properties of functional walk tests used in the cardiorespiratory domain. Chest. 2001; 119: 256-70.

40. Li AM, Yin J, Au JT, So HK, Tsang T, Wong E, et al. Standard reference for the six-minute-walk test in healthy children aged 7 to 16 years. Am J Respir Crit Care Med. 2007; 176: 174-80.

41. Geiger R, Strasak A, Treml B, Gasser K, Kleinsasser A, Fischer V, et al. Six-minute walk test in children and adolescents. J Pediatr. 2007; 150: 395-9, 99 e1-2.

42. Gulmans VA, van Veldhoven NH, de Meer K, Helders PJ. The six-minute walking test in children with cystic fibrosis: reliability and validity. Pediatr Pulmonol. 1996; 22: 85-9.

43. Larsson UE, Reynisdottir S. The six-minute walk test in outpatients with obesity: reproducibility and known group validity. Physiother Res Int. 2008; 13: 84-93.

44. Li AM, Yin J, Yu CC, Tsang T, So HK, Wong E, et al. The six-minute walk test in healthy children: reliability and validity. Eur Respir J. 2005; 25: 1057-60.

45. Calders P, Deforche B, Verschelde S, Bouckaert J, Chevalier F, Bassle E, et al. Predictors of 6-minute walk test and 12-minute walk/run test in obese children and adolescents. Eur J Pediatr. 2008; 167: 563-8.

46. Morinder G, Mattsson E, Sollander C, Marcus C, Larsson UE. Six-minute walk test in obese children and adolescents: reproducibility and validity. Physiother Res Int. 2009; 14: 91-104.

47. Elloumi M, Makni E, Ounis OB, Moalla W, Zbidi A, Zaoueli M, et al. Six-minute walking test and the assessment of cardiorespiratory responses during weight-loss programmes in obese children. Physiother Res Int. 2011; 16: 32-42.

48. Geiger R, Willeit J, Rummel M, Hogler W, Stubing K, Strasak A, et al. Six-minute walk distance in overweight children and adolescents: effects of a weight-reducing program. J Pediatr. 2011; 158: 447-51.

49. Makni E, Moalla W, Trabelsi Y, Lac G, Brun JF, Tabka Z, et al. Six-minute walking test predicts maximal fat oxidation in obese children. Int J Obes (Lond). 2012; 36: 908-13.

50. Leger L, Mercier D, Gadoury C, Lambert J. The mutistage 20 metre shuttle run test for aerobic fitness. Journal of Sports Science. 1988; 6: 93-101.

51. Castro-Pinero J, Padilla-Moledo C, Ortega FB, Moliner-Urdiales D, Keating X, Ruiz JR. Cardiorespiratory fitness and fatness are associated with health complaints and health risk behaviors in youth. J Phys Act Health. 2011; 9: 642-9.

52. Quinart S, Mougin F, Simon-Rigaud ML, Nicolet-Guenat M, Negre V, Regnard J. Evaluation of cardiorespiratory fitness using three field tests in obese adolescents: Validity, sensitivity and prediction of peak V O2. J Sci Med Sport. 2013; 17: 521-5.

53. Health GW. Behavioral approaches tp physical activity promotion. In: Ehrman JK, Gordon PM, Visich PS, Keteyian SJ (eds.). Clinical Exercise Physiology. Human Kinetics: Champaign IL 2008; 18-19.

54. Visich PS, Ehrman JK. Graded exercise testing and exercise prescription. In: Ehrman JK, Gordon PM, Visich PS, Keteyian SJ (eds.). Clinical Exercise Physiology. Human Kinetics: Champaign IL 2008; 95.

55. Tsiros MD, Buckley JD, Howe PR, Walkley J, Hills AP, Coates AM. Musculoskeletal pain in obese compared with healthy-weight children. Clin J Pain. 2014; 30: 583-8.

56. Smith SM, Sumar B, Dixon KA. Musculoskeletal pain in overweight and obese children. Int J Obes (Lond). 2014; 38: 11-5.

57. Krul M, van der Wouden JC, Schellevis FG, van Suijlekom-Smit LW, Koes BW. Musculoskeletal problems in overweight and obese children. Ann Fam Med. 2009; 7: 352-6.

58. Parameswaran K, Todd DC, Soth M. Altered respiratory physiology in obesity. Can Respir J. 2006; 13: 203-10.

59. Schiel R, Beltschikow W, Kramer G, Stein G. Overweight, obesity and elevated blood pressure in children and adolescents. Eur J Med Res. 2006; 11: 97-101.

60. Sinha R, Fisch G, Teague B, Tamborlane WV, Banyas B, Allen K, et al. Prevalence of impaired glucose tolerance among children and adolescents with marked obesity. N Engl J Med. 2002; 346: 802-10.

61. Wang LY, Cerny FJ. Ventilatory response to exercise in simulated obesity by chest loading. Med Sci Sports Exerc. 2004; 36: 780-6.

62. Chlif M, Keochkerian D, Feki Y, Vaidie A, Choquet D, Ahmaidi S. Inspiratory muscle activity during incremental exercise in obese men. Int J Obes (Lond). 2007; 31: 1456-63.

63. Cooper DM, Kaplan MR, Baumgarten L, Weiler-Ravell D, Whipp BJ, Wasserman K. Coupling of ventilation and CO2 production during exercise in children. Pediatr Res. 1987; 21: 568-72.

64. Rowland TW, Cunningham LN. Development of ventilatory responses to exercise in normal white children. A longitudinal study. Chest. 1997; 111: 327-32.

65. Mead J. Dysanapsis in normal lungs assessed by the relationship between maximal flow, static recoil, and vital capacity. Am Rev Respir Dis. 1980; 121: 339-42.

66. Gibson N, Johnston K, Bear N, Stick S, Logie K, Hall GL. Expiratory flow limitation and breathing strategies in overweight adolescents during submaximal exercise. Int J Obes (Lond). 2014; 38: 22-6.

67. Belanger K, Breithaupt P, Ferraro ZM, Barrowman N, Rutherford J, Hadjiyannakis S, et al. Do obese children perceive submaximal and maximal exertion differently? Clin Med Insights Pediatr. 2013; 7: 35-40.

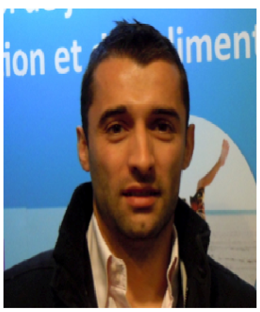
68. Ward DS, Bar-Or O. Usefulness of Borg scale in exercise prescription for overweight youth. . Canadian Journal of Sport Science. 1990; 15: 120-25.

Julien Aucouturier

Julien Aucouturier is assistant professor at the Faculty of Sports Sciences and Physical Education, at Lille 2 University (France). Since his PhD, he has been working on the link between physical activity and metabolic health in children, with a particular interest for the metabolic responses to exercise and food intake in obese people. His other research interests are in the field of training and nutrition for sports performance.

Julien Aucouturier is a member of the “Physical Activity, Muscle, Health” Laboratory where investigations are conducted on topics such as the health benefits of physical activity, the physiological factors limiting performances, dysfunction of the neuromuscular system and its adaptation to exercise.

David Thivel



David Thivel is Assistant Professor at the Faculty of Sports Sciences at Blaise Pascal University (Clermont-Ferrand, France). He completed a PhD in Exercise Physiology and Human Nutrition in 2011 at French the National Institute for Agronomic Research and Blaise Pascal University of Clermont-Ferrand. He mainly explores the impact of physical activity on the behavioral and physiological control of energy intake and appetite in lean and obese children and adolescents. His other research interests are in the field of physical fitness, body composition and metabolic health in pediatric populations.

David Thivel is a member of the AME2P Laboratory of Clermont-Ferrand (Metabolic Adaptations to Exercise under Physiological and Pathological conditions) and is particularly involved in its “Energy Metabolism” research group.