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LITERATURE REVIEW

Exercise testing and training in chronic childhood conditions†

Tim Takken, PhD*, Erik H. Hulzebos, PT, PhD

Child Development and Exercise Centre, Wilhelmina Children's Hospital, University Medical Centre Utrecht, Utrecht, The Netherlands

KEYWORDS
activity;
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Abstract Physical fitness is an important element of clinical exercise physiology. It is a multidimensional concept that has been defined as a set of attributes that people possess or achieve to perform physical activity. Many children with a chronic condition or disability have a hypoactive lifestyle. However, physical fitness and physical activity is just as, or even more, important in children with chronic conditions as in healthy children. Therefore, children with a chronic condition should not be "sidelined", but should actively participate in physical activity/sports.

Introduction

Paediatric health professionals have acknowledged the use of exercise in the prevention, diagnosis, and treatment of chronic childhood conditions and related health problems [1,2]. Physical fitness is an important element of clinical exercise physiology. It is a multidimensional concept (Fig. 1), that has been defined as a set of attributes that people possess or achieve to perform physical activity [3]. In contrast to healthy children, children with a chronic condition are often constrained from participation in physical activities or sports programs, as a consequence of real or perceived limitations imposed by their condition. The condition itself often causes hypoactivity, which leads to a deconditioning effect, a reduction in the functional ability, and further hypoactivity [4]. Not only might physical fitness and functional ability decrease due to hypoactivity, these children also are at additional risk for a variety of health conditions associated with a hypoactive lifestyle (e.g., obesity, diabetes). In this paper, we briefly review methods for fitness testing in children with chronic conditions, as well as possibilities for exercise training in the paediatric physical therapeutic setting.

* Corresponding author. Child Development and Exercise Centre, Wilhelmina Children's Hospital, University Medical Centre Utrecht, P.O. Box 85090, NL-3508 AB Utrecht, The Netherlands.
E-mail address: t.takken@umcutrecht.nl (T. Takken).
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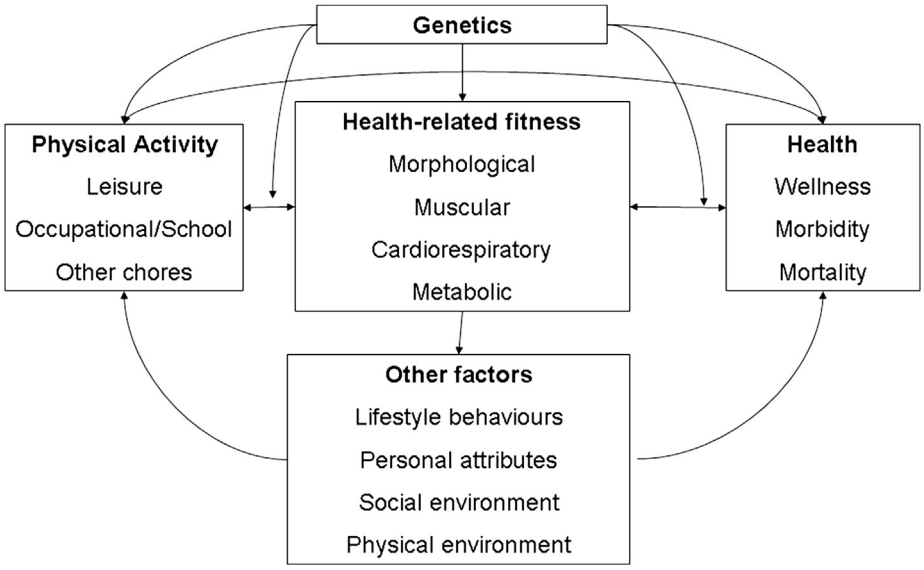

Figure 1 Model linking physical activity, health-related fitness, and health. *Note*. Adapted from "*Physical activity and health*" by C. Bouchard, S.N. Blair, W.L Haskell, 2012, Champaign: Human Kinetics Publishers, p. 18. Copyright 2012, Human Kinetics Publishers.

Fitness testing

In fitness testing, we distinguish the measurement of health-related fitness and performance-related fitness. Health-related fitness consists of, among others, aerobic fitness (peak oxygen uptake) and muscle strength (Table 1). Performance-related fitness consists of, among others, activity capacity measured using performance tests and anaerobic fitness. Here, we will describe both the measurement of health-related fitness and performance-related fitness.

Health-related fitness

Aerobic fitness

The highest oxygen uptake attained during a graded maximal exercise to volitional exhaustion (VO_{2peak}) is considered as the single best indicator of aerobic fitness by the World Health Organization [5]. VO_{2peak} is the reflection of the maximal oxygen flux through the lungs, transported by the circulation to the mitochondria of the exercising muscle. The VO_{2peak} is the only index that integrates pulmonary, circulatory, and muscular function into one single number (Fig. 2).

Based on the Fick principle, VO_{2peak} is the product of cardiac output (heart rate $\times$ stroke volume) and the mixed arteriovenous oxygen difference [6]. Thus, VO_{2peak} is dependent on cardiac function, the ability of the lungs to bind oxygen to the blood, and the ability of the muscles to extract (utilise) oxygen from the circulation.

Exercise testing in paediatrics differs in many aspects from the tests performed in adults. Diseases that are associated with myocardial ischemia are very rare in children. Children's cardiovascular responses to exercise present different characteristics, particularly oxygen uptake, heart rate, and blood pressure response during exercise. The main indications for exercise testing in children are an

Table 1 The components and factors of health-related fitness

Morphological components	Muscular components	Motor components	Cardiorespiratory components	Metabolic components
Body mass for height	Power	Agility	Submaximal exercise capacity	Glucose tolerance
Body composition	Strength	Balance	Maximal aerobic exercise capacity	Insulin sensitivity
Subcutaneous fat distribution	Endurance	Coordination	Cardiac function	Lipid and lipoprotein metabolism
Abdominal visceral fat		Speed of movement	Lung function	Substrate oxidation characteristics
Bone density			Blood pressure	
Flexibility				

Note. Modified from "*Physical activity and health*" by C. Bouchard, S.N. Blair, and W.L Haskell, 2012, Champaign: Human Kinetics Publishers, p. 16. Copyright 2012, Human Kinetics Publishers.

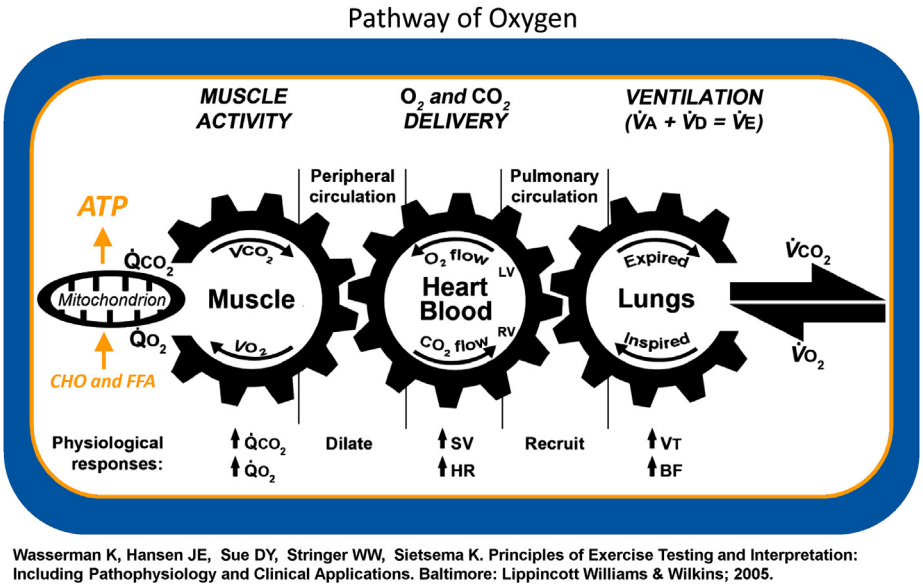

Figure 2 The pathway of oxygen in the human body. Inhaled oxygen (O_2) is bound in the lungs to the blood. The heart pumps the blood to the active muscles, where free fatty acids (FFA) and carbohydrates (CHO) are oxidized using O_2 in the mitochondria. Carbon dioxide (CO_2) is produced during this process, and bound to the blood and transported back to the lungs, where CO_2 is expired.

evaluation of exercise capacity, long-term follow-up, an evaluation of (training) interventions, and the identification of exercise-induced arrhythmias or syncope.

The gold standard for determining VO_{2peak} in an individual is by the determination of oxygen (O_2) and carbon dioxide (CO_2) concentrations in expired air at regular intervals during graded exercise on an ergometer. There are many test protocols available for maximal exercise testing in children. The Bruce protocol on the treadmill and the Godfrey protocol on the cycle ergometer are the most frequently used test protocols in paediatrics [7]. However, it is important to note that there are several "disease specific" maximal exercise testing protocols, for example, for children with cystic fibrosis [8], spina bifida [9], and cerebral palsy [10]. A detailed description of protocols and equipment can be found in other articles [11,12]. Also, field testing protocols are available, based on modifications of the original shuttle run tests [13] or cycle ergometry [14,15]. For wheelchair-bound children, a shuttle ride test can be used [2].

Muscle strength

Although there are a several tests available for measuring muscle strength in children, it is still difficult to recommend a test for measuring improvement in strength during exercise interventions. There is a wide range of procedures available, including isokinetic dynamometry, hand-held dynamometry, and functional muscle strength tests. However, the clinimetric properties of these tests have not been studied in many paediatric conditions. On many occasions, adult procedures and data have been used in children [15]. We have observed good interobserver, intraobserver, and test–retest reliability of three functional muscle strength tests for children and adolescents with cerebral palsy [16]. However, it is unknown whether these tests are valid and reliable in other paediatric conditions.

Performance-related fitness

For the evaluation of performance-related fitness, the 6-minute walk test is the most frequently used test in clinical populations [17,18]. In many patients, the 6-minute walk test performance is not related to aerobic fitness [19], it is only related to aerobic fitness in children with a severely reduced walking ability of less than 350 meters [20]. For wheelchair bound children, a 6-minute ride test can be used [21]. Other performance tests include timed up and down stairs test, and timed up and go test. In addition, several individual items of the Bruininks-Oseretsky Test of Motor Proficiency can be used [22].

Anaerobic fitness

In the laboratory setting, anaerobic fitness is usually measured using the Wingate anaerobic test. This is a 30-seconds all-out test on the cycle ergometer [23]. Various studies have shown that many children with chronic disease have a reduced anaerobic fitness compared to their peers. One of the drawbacks of this test is that it requires a specialized ergometer and software and no published normative values for children are available. Therefore, field tests for anaerobic fitness are of interest for the paediatric physical therapist. Examples of tests are the muscle power sprint test and 10 × 5 m sprint test [24,25].

Training

Evidence is increasing to suggest that physical fitness training is important for the group of children with chronic

conditions [26]. However, little information is available on the clinical characteristics of the child that predict a response to such an intervention.

For the clinician, it is important to have guidelines for selecting which children may benefit from an exercise program. These include determining whether deconditioning is due to inactivity, medication and nutritional status, disease-related pathophysiology, or a combination of these factors.

We recommend using the so-called F.I.T.T. factors (frequency, intensity, time, and type) as a guideline for a child and disease-specific training program.

For children with a chronic condition, the following general F.I.T.T. factors can be obtained from the literature [27]. The training frequency should be a minimal two times per week, and intensity should be higher than 66% of peak heart rate and last for 20—60 minutes per session, in which the large muscle groups have to be used. Training programs should last for about 12 consecutive weeks [27]. Guidelines for healthy children are listed in Table 2. However, there is no "one-size-fits-all" guideline for children with a chronic condition.

Furthermore, the possible higher fatigue values, slower recovery time, and slower adaptation time in children with a chronic condition should be considered. Some conditions benefit from longer physical training programs. Always consider the type of activity, which should be suited to the specific chronic condition. Finally, adherence to exercise programs depends on individual motivation and variation in activities. Children and adolescents are more likely to enjoy short-term, high-intensity exercises (when possible), because they usually offer the necessary variations and they better mimic the usual daily activity pattern of children.

High-intensity exercise training

A new exercise training paradigm in clinical exercise physiology is high-intensity training (HIT). During HIT there is a systematic alternation between work (exercise) and (active) recovery. This alternation means that skeletal muscles, heart, and vessels are given an effective training dose.

Various studies in adult clinical populations have shown that HIT is an effective training paradigm to achieve a large effect in a short timeframe. These effects are gained in a much shorter timeframe compared to traditional submaximal endurance training [28]. We have shown in a case report of a 16-year-old girl with cystic fibrosis that a 5-week period of HIT could result in clinically relevant changes in exercise capacity [29].

Table 2 Training guidelines for healthy children

	Aerobic training	Strength training
Frequency	$\geq$3 days/wk	2—3 days/wk
Intensity	All out principle (HIT) >80% HR_{peak}	50—70% 1 RM
Time (session)	30—60 min	1—2 sets $\times$ 10—15 reps
Program duration	8—12 wk	6—12 wk

Note. Recommendations are based on "Endurance training and aerobic fitness in young people" by G. Baquet, E. van Praagh, and S. Berthoin, 2003, Sports Med, 33, p. 11; and "Youth resistance training: updated position statement paper from the national strength and conditioning association" by A.D. Faigenbaum, W.J. Kraemer, C.J. Blimkie, I. Jeffreys, L.J. Micheli, M. Nitka et al. 2009, J Strength Cond Res, 23.
HIT = high-intensity training; RM = repetition maximum; HRpeak = peak heart rate.

Catabolism/anabolism

Clinical exercise experts face a dilemma in prescribing exercise programs for children with a chronic condition, because in various conditions, exercise may improve health in part by stimulating growth factors and tissue anabolism. By contrast, it is also known that the same process of exercise, if sufficiently intense, can stimulate inflammatory cytokines and lead to a catabolic state [30—33]. Finding the optimal level of physical activity in children and adolescents with a chronic (inflammatory) condition can be difficult, because the underlying disease can be associated with increased basal energy, malnutrition, and inflammation, all of which promote tissue catabolism even at rest [34]. This dilemma shows the problems faced for implementing exercise therapy for children with a variety of inflammatory/catabolic conditions (such as arthritis, cystic fibrosis, and cancer). However, the role of exercise as therapy in children with a variety of chronic conditions, is becoming increasingly recognised, even in patients with inflammatory conditions [35].

Physical activity

An interesting tool for the prescription of physical activity in children is the children's physical activity pyramid (Fig. 3), which is similar to the food pyramid for nutrition. It is recommended that children and adolescents should participate daily in $\geq$60 minutes of moderate to vigorous physical activity that is developmentally appropriate, enjoyable, and involves a variety of activities. In addition, screen-time should be limited to a maximum of 2 hours per day [36].

However, today, many children with a chronic condition still encounter many barriers in performing physical activities in their daily life. Many sport clubs, physical education classes, or extracurricular programs, are not equipped to have these children participate in their programs. Physical therapists should therefore not only inform parents about the importance of sufficient and appropriate levels of physical activity for children with a chronic condition, but caregivers, healthcare professionals, trainers, and teachers should also be informed [26,37].

In conclusion, physical fitness and physical activity is just as important in children with chronic conditions as in healthy children. Therefore, children with a chronic condition should not be "sidelined", but should activity participate in physical activity/sports. This is a difficult task for paediatric physical therapists.

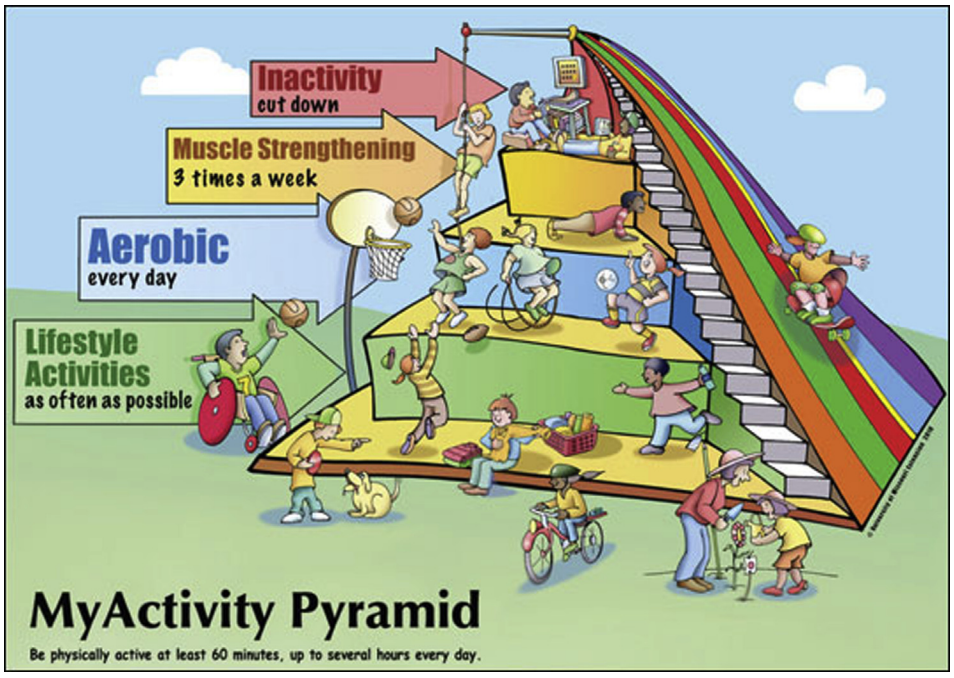

Figure 3 Children's physical activity pyramid. *Note*. From http://extension.missouri.edu/p/n386, MU Extension. Copyright 1993—2013, University of Missouri. Reproduced with permission. 2012. [accessed 01.06.13].

References

[1] Verschuren O, Zwinkels M, Ketelaar M, Reijnders-van Son F, Takken T. Reproducibility and validity of the 10-meter shuttle ride test in wheelchair-using children and adolescents with cerebral palsy. Phys Ther 2013 May 16 [Epub ahead of print].

[2] van Brussel M, van der Net J, Hulzebos E, Helders PJ, Takken T. The Utrecht approach to exercise in chronic childhood conditions: the decade in review. Pediatr Phys Ther 2011;23:2—14.

[3] Caspersen CJ, Powell KE, Christenson GM. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. Public Health Rep 1985;100: 126—31.

[4] Bar-Or O, Rowland TW. Pediatric exercise medicine: from physiologic principles to health care application. Champaign: Human Kinetics; 2004.

[5] Shephard RJ, Allen C, Benade AJ, Davies CT, Di Prampero PE, Hedman R, et al. The maximum oxygen intake. An international reference standard of cardiorespiratory fitness. Bull World Health Organ 1968;38:757—64.

[6] Fick A. Ueber die Messung des Blutquantums in den Herzventrikeln. Wurzburg: Sitx der Physik-Med Ges 1870;16. (In German).

[7] Paridon SM, Alpert BS, Boas SR, Cabrera ME, Caldarera LL, Daniels SR, et al. Clinical stress testing in the pediatric age group. A statement from the American Heart Association Council on Cardiovascular Disease in the Young, Committee on Atherosclerosis, Hypertension, and Obesity in Youth. Circulation 2006;113:1905—20.

[8] Hulzebos HJ, Werkman MS, van Brussel M, Takken T. Towards an individualized protocol for workload increments in cardiopulmonary exercise testing in children and adolescents with cystic fibrosis. J Cyst Fibros 2012;11:550—4.

[9] de Groot JF, Takken T, de Graaff S, Gooskens RH, Helders PJ, Vanhees L. Treadmill testing of children who have spina bifida and are ambulatory: does peak oxygen uptake reflect maximum oxygen uptake? Phys Ther 2009;89:679—87.

[10] Verschuren O, Takken T, Ketelaar M, Gorter J, Helders P. Reliability and validity of data for 2 newly developed shuttle run tests in children with cerebral palsy. Phys Ther 2006;86:1107—17.

[11] Takken T, Blank AC, Hulzebos EH, van Brussel M, Groen WG, Helders PJ. Cardiopulmonary exercise testing in congenital heart disease: (contra)indications and interpretation. Neth Heart J 2009;17:385—92.

[12] Takken T, Blank AC, Hulzebos EH, van Brussel M, Groen WG, Helders PJ. Cardiopulmonary exercise testing in congenital heart disease: equipment and test protocols. Neth Heart J 2009;17:339—44.

[13] De Backer IC, Singh-Grewal D, Helders PJ, Takken T. Can peak work rate predict peak oxygen uptake in children with juvenile idiopathic arthritis? Arthritis Care Res (Hoboken) 2010;62: 960—4.

[14] Bongers BC, de Vries SI, Helders PJ, Takken T. The steep ramp test in healthy children and adolescents: reliability and validity. Med Sci Sports Exerc 2013;45:366—71.

[15] Jones MA, Stratton G. Muscle function assessment in children. Acta Paediatrica 2000;89:753—61.

[16] Verschuren O, Ketelaar M, Takken T, Van Brussel M, Helders P, Gorter J. Reliability of hand-held dynamometry and functional strength tests for the lower extremity in children with cerebral palsy. Disabil Rehabil 2008;30:1358—66.

[17] de Groot JF, Takken T. The six-minute walk test in paediatric populations. J Physiother 2011;57:128.

[18] Bartels B, de Groot JF, Terwee CB. The six-minute walk test in chronic pediatric conditions: a systematic review of measurement properties. Phys Ther 2013;93:529—41.

[19] Takken T. Six-minute walk test is a poor predictor of maximum oxygen uptake in children. Acta Paediatr 2010;99:958. author reply 958—9.

[20] Lammers AE, Diller GP, Odendaal D, Tailor S, Derrick G, Haworth SG. Comparison of 6-min walk test distance and cardiopulmonary exercise test performance in children with pulmonary hypertension. Arch Dis Child 2011;96:141—7.

[21] Verschuren O, Ketelaar M, De Groot J, Vila Nova F, Takken T. Reproducibility of two functional field exercise tests for

children with cerebral palsy who self-propel a manual wheelchair. Dev Med Child Neurol 2013;55:185—90.
[22] Deitz JC, Kartin D, Kopp K. Review of the Bruininks-Oseretsky Test of Motor Proficiency, second edition (BOT-2). Phys Occup Ther Pediatr 2007;27:87—102.
[23] Aasland A, Flato B, Vandvik IH. Psychosocial outcome in juvenile chronic arthritis: a nine year follow-up. Clin Exp Rheumatol 1997;15:561—8.
[24] Verschuren O, Bongers BC, Obeid J, Ruyten T, Takken T. Validity of the muscle power sprint test in ambulatory youth with cerebral palsy. Pediatr Phys Ther 2013;25:25—8.
[25] Verschuren O, Takken T, Ketelaar M, Gorter J, Helders P. Reliability for running tests for measuring agility and anaerobic muscle power in children and adolescents with cerebral palsy. Pediatr Phys Ther 2007;19:108—15.
[26] Edouard P, Gautheron V, D'Anjou MC, Pupier L, Devillard X. Training programs for children: literature review. Ann Readapt Med Phys 2007;50:510—9. 499—509.
[27] Baquet G, van Praagh E, Berthoin S. Endurance training and aerobic fitness in young people. Sports Med 2003;33:1127—43.
[28] Gibala MJ, Little JP, Macdonald MJ, Hawley JA. Physiological adaptations to low-volume, high-intensity interval training in health and disease. J Physiol 2012;590(Pt 5):1077—84.
[29] Hulzebos HJ, Snieder H, van der Net J, Helders PJ, Takken T. High-intensity interval training in an adolescent with cystic fibrosis: a physiological perspective. Physiother Theory Pract 2011;27:231—7.
[30] Eliakim A, Brasel JA, Mohan S, Barstow TJ, Berman N, Cooper DM. Physical fitness, endurance training, and growth hormone-insulin-like growth factor I system in adolescent females. J Clin Endocrinol Metab 1996;81:3986—92.
[31] Scheett TP, Mills PJ, Zieger MG, Stoppani J, Cooper DM. Effects of exercise on cytokines and growth mediators in prepubertal children. Pediatr Res 1999;46:429—34.
[32] Theintz GE, Howald H, Weiss U, Sizonenko PC. Evidence for a reduction of growth potential in adolescent female gymnasts. J Pediatr 1993;122:306—13.
[33] Eliakim A, Brasel JA, Mohan S, Wong WL, Cooper DM. Increased physical activity and the growth hormone-IGF-I axis in adolescent males. Am J Physiol 1998;275:R308—14.
[34] Cooper DM, Nemet D, Galassetti P. Exercise, stress and inflammation in the growing child: from the bench to the playground. Curr Opin Pediatr 2004;16:286—92.
[35] Ploeger H, Takken T, de Greef M, Timmons B. The effects of acute and chronic exercise on inflammatory markers in children and adults with a chronic inflammatory disease: a systematic review. Exerc Immunol Rev 2009;15:6—41.
[36] Strong WB, Malina RM, Blimkie CJR, Daniels SR, Dishman RK, Gutin B, et al. Evidence based physical activity for school-age youth. J Pediatr 2005;146:732—7.
[37] Murphy NA, Carbone PS, the Council on Children with Disabilities. Promoting the participation of children with disabilities in sports, recreation, and physical activities. Pediatrics 2008;121:1057—61.