

Modified Treadmill Protocol for Evaluation of Physical Fitness in Pediatric Age Group - Comparison with Bruce and Balke Protocols

B. Marinov¹, S. Kostianev¹, T. Turnovska², ¹Department of Pathophysiology and ²Department of Hygiene & Ecology, Higher Medical Institute, Plovdiv, Bulgaria.

The aim of this study was to compare classical Balke and Bruce protocols with our modification of Balke protocol in pediatric cardiorespiratory diagnostics. The modification of Balke consists of nine stages per 1 min at a constant velocity of 5.6 km.h⁻¹ and increasing elevation from 6% to 22% in 2% increments.

Sixty healthy children (mean age=13.3±0.2 years; BMI=18.8±0.6 kg.m⁻²; mean ± 95% CI), divided into three groups of 20 children each, matched by age, height and BMI performed integrative cardiopulmonary exercise testing using one of the treadmill protocols mentioned. At the end of each exercise increment and throughout the recovery period the children were asked to rate the perceived exertion (RPE) using the Borg Category Ratio scale - CR-10.

Exercise results showed that Balke protocol had the longest duration (21.7±0.6 min.) and the lowest values for VO₂/kg (34.2±1.8 ml.min⁻¹.kg⁻¹) due to the minimal workload increments. Bruce protocol had intermediate duration (14.9±1.1 min.) and children achieved the highest VO₂/kg (48.6±2.7 ml.min⁻¹.kg⁻¹) but the test is symptom-limited which is ethically unacceptable in childhood. Exercise data revealed that our modification of the classical Balke protocol had an optimal duration (11 min.) and yielded peak VO₂/kg values (39.4±2.3 ml.min⁻¹.kg⁻¹) adequate for evaluation of children's exercise capacity. Children's ratings of perceived exertion were highest in Bruce protocol (6.5±0.4) and lowest in the original Balke protocol (4.5±0.8).

In conclusion, the modification of Balke protocol is suitable and reliable for screening and clinical testing in pediatric age group. *Acta Physiol. Pharmacol. Bulg.*, 27 (2003) 1-pp.

KEY WORDS: Treadmill protocols; Exercise tolerance in children; Perceived exertion; Borg score.

Received February 21, 2002

INTRODUCTION

Cardiopulmonary exercise testing not only measures the efficiency and capacity of the oxygen transport systems but can also reveal the causes for children's exercise limitation (Armstrong and Welsman, 1994). Historically, the protocols used for exercise testing have been based on tradition, convenience or both. In the past decade a considerable amount of research has focused on the effect of the exercise protocol on test performance, including exercise tolerance, diagnostic accuracy and gas exchange (Myers et al., 2000). Children's performance largely depends on the exercise modality and the testing protocol (Washing-

ton et al., 1994), though special considerations have to be taken to tailor the workload to pediatric population and ensure standard conditions. There are several widely used treadmill protocols for assessment of children's physical capacity but none of them is compliant with the modern guidelines for paediatric exercise testing (Washington et al., 1994). Therefore there is a necessity of a treadmill protocol appropriate either for a clinical use or as a reliable screening method. Such protocol is intended to avoid both an excessive duration and excessive workload increments (Myers et al., 1991; Buchfuhrer et al., 1983). Since pediatric patients are of various ages and sizes, sometimes disabled with respect to mobility and muscular coordination the new protocol must be designed to change either speed or grade from one stage to the next (Lehman et al., 1997)

The aim of this study was to compare classical Bruce and Balke treadmill protocols with our modi-

Corresponding author: Blagoi Marinov, MD, 15A Vasil Aprilov Blvd, Higher Medical Institute, Pathophysiology Department, Plovdiv 4002, Bulgaria. **Phone:** (+359 32) 602227; **e-mail:** blim@plovdiv.techno-link.com

fication of Balke protocol in pediatric population, as well as to elucidate the applicability of the new protocol in practice.

MATERIALS AND METHODS

Sixty healthy children (mean age 13.3 ± 0.2 years), divided into three groups of 20 children each, matched by age, height and BMI (Table 1) performed integrative cardiopulmonary exercise testing using one of the following treadmill protocols:

- Balke protocol (Balke and Ware, 1959) – constant velocity of 3.5 mph (5.6 km/h) and 1% increments each minute till 22%.
- Bruce protocol (Bruce, 1971) – simultaneously changing speed and grade in 3 minutes intervals.
- Modified Balke protocol (Marinov et al., 2000) – consisting of nine stages per 1 min at a constant velocity of 5.6 km/h and increasing elevation from 6% to 22% in 2% increments each minute.

Graphical presentation of the three applied protocols is shown on Fig. 1.

All of the children were in good health, physically active but not engaged in a regular endurance training activities. Prior to the test all the participants underwent comprehensive pulmonary function assessment: conventional spirometric tests (slow vital capacity and forced vital capacity) and maximal inspiratory pressure (P_Imax) with MasterScreen Diffusion™ (Jaeger, Wuerzburg, Germany) in a certified laboratory applying the ERS (Statement, 1993) and ATS (Statement, 1995) criteria to ensure quality. All measurements were performed in a seated position with a nose clip. Thorough anthropometric measurements were performed as well.

The treadmill test was performed in the morning in a laboratory compliant with the modern guidelines (Pina et al., 1995). The children were habituated to both the general environment and the actual test procedures. The exercise test was carried out on a motor driven, electronically controlled treadmill (TrackMasterä, USA) and gas exchange variables were determined with an on-line computerized system Cardiol₂™ (Medical Graphics, MN, USA) using standard open circuit techniques. Subjects breathed through a mouthpiece and a pneumotachometer was used for recording tidal volume (V_T ; ml.min⁻¹, BTPS) and minute ventilation (V_E ; L.min⁻¹, BTPS). Expired gas samples were analyzed for oxygen and carbon dioxide by zirconium oxide and infrared analyzers, respectively. Data were averaged every 30 sec and were used to calculate oxygen uptake ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$) and respiratory exchange

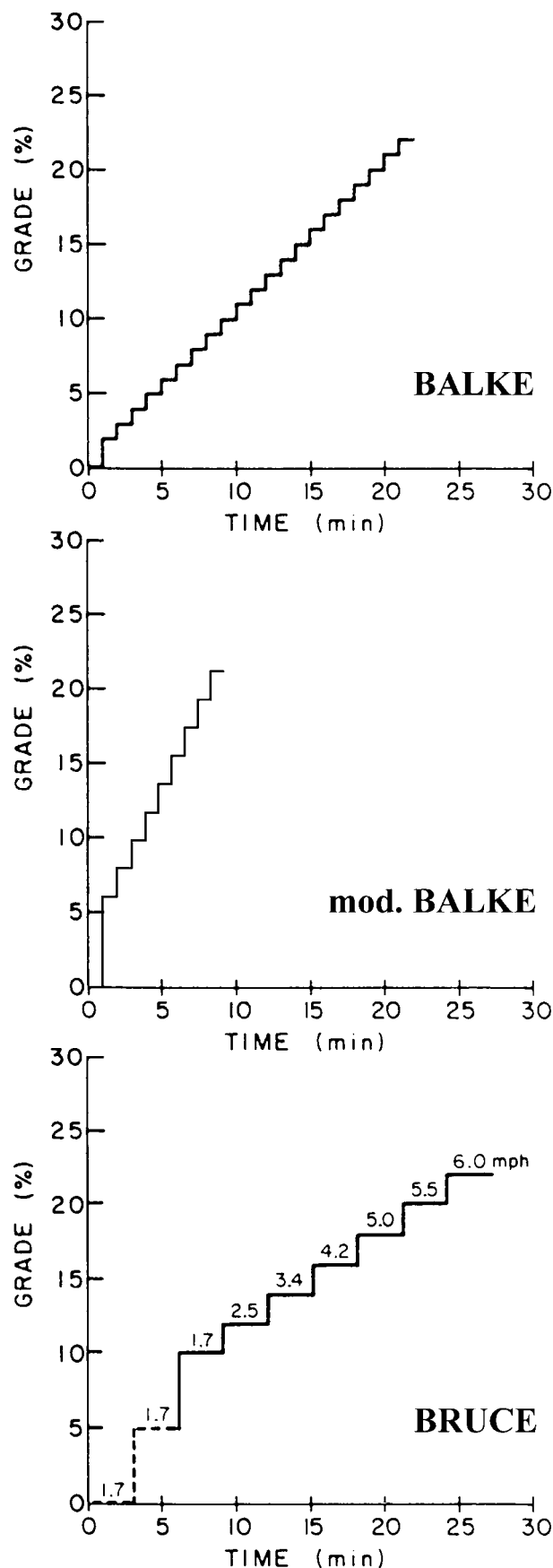


Fig. 1. Graphical presentation of the applied treadmill exercise protocols.

ratio (RER). The system was calibrated before each test. Heart rate was monitored electrocardiographically (Hellige, Germany).

At the end of each exercise increment and throughout the recovery period the children were asked to rate the perceived exertion (RPE) using the Borg Category Ratio scale - CR-10 (Borg, 1982) depicting fatigue (dyspnea) from "not at all" to "maximal" by means of ten grades.

Changes in anthropometrical and peak exercise variables were assessed with regard to the groups studied and different protocols using descriptive statistics of SPSS for Windows (SPSS, Chicago, IL, USA). Multiple comparisons between groups were made by means of one way ANOVA. Values are expressed as a mean \pm 95% confidence interval.

RESULTS

The anthropometric and peak exercise data for the studied groups are presented on Table 1.

No significant differences were found in the anthropometric parameters. The main spirometric indices for all children studied were in the reference limits - forced expiratory volume in one second $FEV_1\% = 103 \pm 2\%$, vital capacity $VC\% = 97 \pm 2\%$, total lung capacity $TLC\% = 99 \pm 2\%$.

Peak exercise results revealed that Balke protocol had the longest duration (21.7 ± 0.6 min) and the lowest values of VO_2/kg (34.2 ± 1.8 $ml \cdot min^{-1} \cdot kg^{-1}$) due to the minimal workload increments. Bruce protocol had intermediate duration (14.9 ± 1.1 min) and chil-

dren achieved the highest VO_2/kg (48.6 ± 2.7 $ml \cdot min^{-1} \cdot kg^{-1}$) but the test is symptom-limited (maximal) which was found to be ethically unacceptable (Harris, 1999). Our modification of the Balke protocol had an optimal duration of 11 min and yielded peak VO_2/kg values (39.4 ± 2.3 $ml \cdot min^{-1} \cdot kg^{-1}$) adequate for evaluation of children's exercise tolerance.

VO_2 kinetics for the three studied protocols are presented on Fig. 2. Ventilatory parameters (tidal volume, breathing frequency and minute ventilation) during exercise were closely related to body size and peak oxygen consumption – the values were highest in Bruce protocol and lowest in the original Balke. The same relationship was observed in Borg score. Children's ratings of perceived exertion were highest in Bruce protocol and lowest in the original Balke.

DISCUSSION

We found that the proposed modification of Balke protocol is compliant with the established standards for cardiopulmonary exercise tests and it is suitable and reliable for testing the exercise tolerance in paediatric age group.

One of the most influential approaches in exercise testing is the choice of the protocol. Recent data have suggested that the protocol can have an important impact on test sensitivity, the reason for test termination, the different slopes calculation, the interpretation of gas exchange responses, and the accuracy with which oxygen uptake is predicted from work rate. Recommendations for optimizing the test

Table 1. Anthropometric and peak exercise data for the studied groups

Parameter	Studied groups			P value
	Bruce	Balke	modified Balke	
Age (years)	13.6 \pm 0.2	13.0 \pm 0.5	13.4 \pm 0.2	NS*
Height (cm)	163.4 \pm 4.7	162.1 \pm 5.3	164.3 \pm 3.0	NS
BMI ($kg \cdot m^{-2}$)	19.1 \pm 0.8	19.7 \pm 2.1	21.0 \pm 1.5	NS
Duration (min)	14.9 \pm 1.1	21.7 \pm 0.6	11.0 \pm 0.0	<0.001
VO_2 peak ($mL \cdot min^{-1}$)	2489 \pm 219	1758 \pm 186	2216 \pm 141	<0.001
VO_2/kg ($mL \cdot kg^{-1} \cdot min^{-1}$)	48.6 \pm 2.7	34.2 \pm 1.8	39.4 \pm 2.3	<0.001
VO_2 pulse ($mL \cdot beat^{-1}$)	12.5 \pm 1.1	9.3 \pm 0.9	12.3 \pm 0.9	<0.001
RER	1.10 \pm 0.03	1.02 \pm 0.04	1.04 \pm 0.03	0.008
V_T (mL)	1585 \pm 139	1312 \pm 204	1563 \pm 156	0.045
BF (min^{-1})	51.4 \pm 4.2	39.9 \pm 3.0	41.1 \pm 2.9	<0.001
V_E ($L \cdot min^{-1}$)	81.0 \pm 8.8	50.5 \pm 5.9	62.3 \pm 5.1	<0.001
V_E/VCO_2	29.6 \pm 1.4	28.2 \pm 1.4	27.1 \pm 1.1	0.030
Borg score	6.5 \pm 0.4	4.5 \pm 0.8	5.2 \pm 0.6	<0.001

NS* – non-significant; BMI – body mass index; BF – breathing frequency

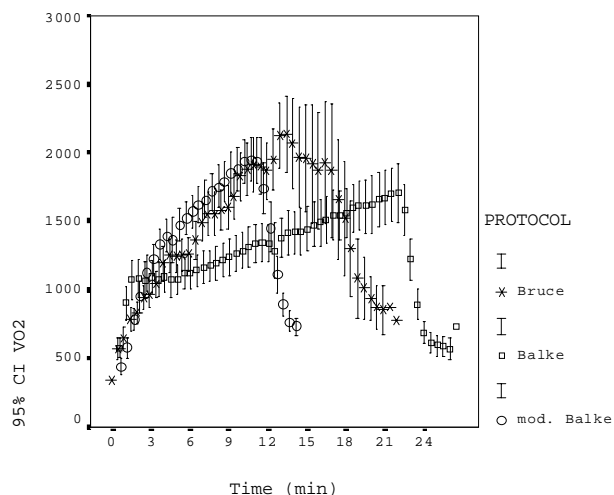


Fig. 2. VO_2 kinetics for the three studied protocols

have focused on the test duration, reducing the increments in work rate, and individualizing the test relative to the purpose of the test and the subject tested (Myers et al., 1992).

The best exercise testing protocol for children depends on the information required and the age, health and fitness level of the subject. That is why we tested healthy subjects who could be expected to pass through as many stages of the studied protocols as possible as a prerequisite for comparability through their entire length (Lehmann et al., 1997). It is evident that classical Balke protocol is unnecessarily long and the slope is too shallow. The classical Bruce is presumed to be suitable for all ages (Cumming et al., 1978) but it is also a bit too long and the simultaneous change of speed and slope appears to be difficult for the younger children. Protocols which contain large and/or unequal increments in work cause a disruption in the normal linear relation between VO_2 and work rate leading to an overprediction of metabolic equivalents. Such protocols can mask the salutary effects of an intervention, and some authors have suggested that the protocol design can influence the diagnostic performance of the test (Myers and Bellin, 2000). One of the most widely used protocols, i. e. Bruce protocol, yields the highest values for VO_2/kg (range $45.9 \pm 61.3 \text{ ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$, Freedson and Goodman, 1993) but they are difficult to achieve because the test is symptom-limited. The modified Balke protocol achieves values for oxygen uptake (VO_2) and oxygen pulse (VO_2 pulse) similar to Bruce at corresponding duration of the protocol.

Guidelines published by major organizations have suggested that the protocol be individualized based on the patient being tested and the purpose of the test (Myers and Bellin, 2000). Data in the literature reveal the following hallmarks of what we call *rationale* for an “ideal” exercise test protocol:

- Submaximal by nature (ethical considerations)
- Simple and easy to perform
- Standardized workload (comparability of results)
- Exercise duration between 8 and 12 min.
- Appropriate for testing healthy children and patients

Our results with the modified Balke and Bruce protocols support the findings of Buchfuhrer et al. (1983) that the VO_2 max was significantly higher on tests where the increment magnitude was large enough to induce test durations of 8-17 min. Thus, for evaluating cardiopulmonary function with incremental exercise testing by either treadmill or cycle, it is appropriate to select a work rate increment to bring the subject to the limit of his tolerance in about 10 min. (Washington et al., 1994). On the other hand, the bulky 3 min. intervals of the Bruce protocol are boring for the children and for assessment of their physical fitness it is acceptable to be substituted with 1 min. increments. Results from Fairsher et al. (1983) show that short-duration incremental exercise tests appear to be reliable, practical methods for assessing exercise performance in normal individuals. In fact choosing 1 min increments leads to better linearity of the responses recorded. Zhang et al. (1991) prove that both the ramp and 1-min step work rate tests had no step pattern in either VO_2 or VCO_2 , and the step pattern for the 2-min and 3-min step tests was attenuated or disappeared at work rates above AT. According to the authors the parameters of aerobic function, and other physiological responses at maximum work rate, are independent of the pattern of work rate increase, provided that the overall rate of work rate increase is the same.

Many studies deal with the exercise capacity in childhood but only some of them touch the perceived exertion issue. Therefore, this investigation is among the few ones exploring the application of rating scales for assessment of exercise perception in children during three different treadmill protocols. We prefer the Category Ratio Borg scale – CT-10 (Borg, 1982), especially when working with children. It is plain and better understood by the youngsters. The natural number sequence makes it easy for the children to define their effort perception. The opportunity to communicate with finger signs is an additional advantage for the subject and simplifies the conduction of the test. Our practice has proven that all the children who are carefully instructed and habituated to the test can reliably rate their perception of fatigue by the ten grades of the Borg scale. As we expected, greater awareness of fatigue was found in the Bruce protocol which is *a priori* symptom-limited.

In conclusion, the proposed modification of Balke protocol is compliant with the established stan-

dards for cardiopulmonary exercise tests and combines higher peak VO₂ values achieved with Bruce with the accessible increase of the workload of Balke protocols. It is suitable and reliable both for screening and clinical testing in paediatric age group.

REFERENCES

- American Thoracic Society** (Statement). (1995). Standardization of spirometry. *Am J Resp Crit Care Med*; 152: 1107-1136.
- Armstrong N, Welsman JR. (1994). Assessment and interpretation of aerobic fitness in children and adolescents. *Exerc Sport Sci Rev*; 22: 435-476.
- Balke J, Ware RW. (1959). An experimental study of "physical fitness" of Air Force personnel. *US Armed Forces Med J*; 10: 675-688.
- Borg GAV. (1982). Psychophysical bases of perceived exertion. *Med Sci Sports Exerc*; 14: 377-381.
- Bruce RA. (1971). Exercise testing of patients with coronary artery disease. *Ann Clin Res*; 3: 323-332.
- Buchfuhrer MJ, Hansen JE, Robinson TE, Sue DY, Wasserman K, Whipp BJ. (1983). Optimizing the exercise protocol for cardiopulmonary assessment. *J Appl Physiol* ; 55(5): 1558-1564.
- Cumming G, Everatt D, Hastman L. Bruce treadmill test in children: normal values in a clinic population. (1978). *Am J Cardiol*; 41: 69-75.
- European Respiratory Society** (Official statement). (1993). Standardized lung function testing. *Eur Resp J*; 6 (Suppl. 16): 5-52.
- Fairshter RD, Walters J, Salness K, Fox M, Minh VD, Wilson AF. (1983) A comparison of incremental exercise tests during cycle and treadmill ergometry. *Med Sci Sports Exerc*; 15(6): 549-554.
- Freedson P, Goodman T. (1993). Measurement of oxygen consumption. In *Pediatric laboratory exercise testing: Clinical guidelines*. Ed. Rowland T. Champaign, Ill: Human Kinetics Publishers.
- Harris J. (1999). The principles of medical ethics and medical research. *Cad Saude Publica*; 15 (Suppl. 1) :7-13.
- Karila C, de Blic J, Waernessyckle S, Benoist MR, Scheinmann P. (2001). Cardiopulmonary exercise testing in children: an individualized protocol for workload increase. *Chest*; 120(1): 81-87.
- Lehman G., S. Schmid, R. Ammer, A. Schomig, E. Alt (1997). Evaluation of a new treadmill exercise protocol. *Chest*, 112: 98-106
- Marinov B, S Kostianev, T Turnovska (2000). Submaximal treadmill test for screening of physical capacity in pediatric age group. *Pediatrics*; XL (2): 38-41.
- Myers J, Bellin D. (2000). Ramp exercise protocols for clinical and cardiopulmonary exercise testing. *Sports Med*; 30(1): 23-29.
- Myers J, Buchanan N, Smith D, Neutel J, Bowes E, Walsh D, Froelicher VF. (1992). Individualized ramp treadmill. Observations on a new protocol. *Chest*; 101 (Suppl. 5):236S-241S.
- Myers J, Buchanan N, Walsh D et al. (1991). Comparison of the ramp versus standard exercise protocols. *J Am Coll Cardiol*; 17: 1334-1342.
- Pina IL, Balady GJ, Hanson P. et al. (1995). Guidelines for clinical exercise testing laboratories. *Circulation*; 91: 912-921
- Washington RL, Bricker JT, Alpert BS. et al. (1994). Guidelines for exercise testing in the pediatric age group. *Circulation*; 90: 2166-2179.
- Wasserman K, Hansen JE, Sue DY, Whipp BJ. (1999). Principles of exercise testing and interpretation. Baltimore: Lippincot, Williams and Wilkins.
- Zhang YY, Johnson MC 2nd, Chow N, Wasserman K. (1991). Effect of exercise testing protocol on parameters of aerobic function. *Med Sci Sports Exerc*; 23(5): 625-630.

