Abstract

The purpose of the study was to assess whether the point of deflection from linearity of heart rate (HRD) could be used as an alternative method to determine the ventilatory threshold (VT) in Indian (Bengali) boys that represents the determination of the anaerobic threshold (AT), and also to standardize an exercise test to be effective in eliciting AT in Indian (Bengali) boys by using HRD. Twenty six (26) boys with a mean age of 12.8 (±1.18) years performed a graded maximal exercise test on a treadmill to determine peak VO₂, HRD and VT. The mean peak VO₂, weight related peak VO₂, peak pulmonary ventilation, and peak heart rate of the boys were found to be 1.75 l/min, 47.1 ml/kg/min, 66.9 l/min and 200.2 beats/min respectively. There were no significant differences between mean VO₂, weight related VO₂, pulmonary ventilation (VE), heart rate and respiratory exchange ratio (RER) that were measured at VT and HRD. The mean VO₂ measured at VT and HRD was found to be 1.46 and 1.45 l/min, which were about 84% and 83% of their respective peak values. Linear regression analysis revealed a correlation of 0.94 (p<0.01) between VO₂ measured at VT and VO₂ measured at HRD, so the present study indicates that the point of deflection from linearity of heart rate (HRD) may be an accurate predictor of VT in most but not all boys. J Physiol Anthropol 26(1): 31–37, 2007 http://www.jstage.jst.go.jp/browse/jpa2 [DOI: 10.2114/jpa2.26.31]

Keywords: anaerobic threshold, Indian boys, heart rate deflection (HRD), peak VO₂, ventilatory threshold (VT)

Introduction

The ventilatory threshold (VT) is the point when pulmonary ventilation begins to increase in a disproportionate manner with respect to the increase in VO₂ during incremental exercise. As exercise intensity increases towards maximum, at some point ventilation increases disproportionately as compared to oxygen consumption. This point is called the ventilatory breakpoint. Whenever exercise intensity increases, oxygen delivery to the muscles no longer supports the oxygen requirements of oxidation. To compensate, more energy is derived from glycolysis (anaerobic glycolysis). This increases lactic acid production and accumulation. This lactic acid combines with sodium bicarbonate and forms sodium lactate, water, and carbon dioxide (CO₂). This CO₂ stimulates chemoreceptors, which ultimately stimulates the inspiratory center in the medulla to increase ventilation. Thus, the ventilatory break point reflects the respiratory response to increased CO₂ levels. Ventilation increases dramatically beyond the ventilatory break point. The misappropriate increase in ventilation without an increase in oxygen consumption led to early speculation that the ventilatory break point might be related to the lactate threshold (Wilmore and Costil, 1994). The ventilatory threshold also reflects an increase in the volume of carbon dioxide produced per minute (VCO₂). The increased VCO₂ was thought to result from excess carbon dioxide being released from bicarbonate buffering of lactic acid. Wasserman and McIlroy (1964) used the term anaerobic threshold to describe this phenomenon because the sudden increase in CO₂ reflected a shift toward more anaerobic metabolism. So the onset of VT represents the point during exercise when anaerobic metabolism begins to contribute significantly to the production of ATP (Wasserman et al., 1973).

Measurement of the ventilatory threshold is a useful method to determine aerobic fitness. It is established that the ventilatory threshold (VT) is a valid marker of aerobic fitness. The ventilatory threshold improves after sports training in children (Fukuoka et al., 1997; Hebestreit et al., 2000).

An increased level of anaerobic metabolism is believed to promote an increment of blood lactate concentration (Wasserman et al., 1973). Therefore, the onset of anaerobic metabolism (the anaerobic threshold) was determined
invasively from the point at which blood lactate concentration begins to accumulate above resting level during exercise of incremental intensity (Wasserman et al., 1973). Central to the theory was the postulated link between the first increase in blood lactate concentration and certain predictable changes in gas exchange parameters. These lead to the inference that the anaerobic (lactate) threshold could be accurately determined from noninvasive ventilatory measurements (Wasserman et al., 1973; Caizzo et al., 1982; Davis et al., 1985). The true nature and significance of an ‘anaerobic threshold’ has been widely debated (Wasserman et al., 1973; Yoshida, 1987; Walsh and Bannister, 1988). Despite many controversies (Hughes et al., 1982; Simon et al., 1986; Farrell and Ivy, 1987), VT has been reported to be correlated to the lactate threshold (Caizzo et al., 1982; Davis et al., 1985) and has been shown to be a valid and reliable indicator of cardio-respiratory fitness in both children and adults (Davis, 1985; Reybrouck et al., 1985; Vago et al., 1987; Mahon and Vaccaro, 1989; Washington, 1989; Hebestreit et al., 2000).

Conconi et al. (1982) established that the anaerobic threshold could be determined in adults by a noninvasive field test based on the relationship of incremental running speed (S) to heart rate (HR). They reported the S-HR relationship was linear from low to sub maximal speeds and curvilinear from submaximal to maximal speeds (Smax). The speed at which the linearity of the S-HR relationship was lost, called the deflection speed (Sd), and the HR at Sd was defined as HRD. The speed of deflection coincides with the beginning of a sharp accumulation of blood lactate (Conconi et al., 1982). Gaisl and Wiesspeiner (1988) reported similar findings in children.

Measurement of the ventilatory threshold or the lactate threshold simply by assessing heart rate during graded exercise has considerable importance in the way that sophisticated laboratory instruments are not necessary. Although the heart rate deflection (HRD) may be assessed in field or laboratory settings, the degree of HR deflection is highly dependent upon the type of protocol used (Bodner and Rhodes, 2000). Whether the point of deflection from linearity (HRD) corresponds to the ventilatory threshold (VT) has not been extensively examined in children except for a few studies (Baraldi et al., 1989; Mahon and Vaccaro, 1991). In this connection, Mahon and Vaccaro (1991) suggested that further research is necessary with regard to optimizing the exercise protocol to determine HRD in children. Gaisl and Hoffman (1990) have proposed guidelines for determining HRD in children. They suggested that 12–16 one-minute exercise stages are necessary to accurately determine the HRD. A protocol of increasing speed with increments of 0.5 km/h per minute is recommended when using a treadmill (Farrell and Ivy, 1987). Recently, the so-called Conconi test has also been modified (Conconi et al., 1996). The starting speed (S) increments after a given distance indicated by a previous protocol (Conconi et al., 1982) have been substituted in the modified protocol by a uniform time based on acceleration of exercise intensity (starting speed).

They (Conconi et al., 1996) proposed the starting speed should be 4–5 km/h for children. On the other hand, genetically Indian children are different in physique and endurance capacity from their European, American, and African counterparts (Krakenbuhl et al., 1985; Chatterjee et al., 1992), so the exercise protocol used to measure endurance capacity including the ventilatory threshold needs standardization. Moreover no literature has so far been available regarding the measurements of the ventilatory threshold and HRD on Indian children. Thus the aims of the present study are

i) to evaluate the use of HRD as an alternative method to assess the ventilatory threshold (VT) in Indian (Bengali) boys that represents the determination of the anaerobic threshold (AT)

ii) to standardize an exercise test to be effective in eliciting AT in Indian (Bengali) boys by using HRD.

Materials and Methods

Subjects

Thirty-four Bengali school boys aged 10 to 14 years of the “Pay & Play Schemes” of the Sports Authority of India, Kolkata, participated in this study. All boys were from the disciplines of football and swimming and had formal training of 1 to 3 years. Among the thirty-four boys, 8 were excluded from the final analysis because of a failure to determine their HRD and VT. The results of the investigation were therefore based on data collected from 26 boys. Before the treadmill exercise test, all subjects were clinically tested by Sports Medicine Doctors of the Sports Authority of India. All the boys were found to be clinically fit. Prior to initial testing, all the selected boys and their parents were given a complete explanation of the purposes, procedures, and potential risks and benefits involved in the present study. They were asked to read and sign a statement. Written consent by parents or legal guardians was also taken, in addition to the children’s own written assent.

Age was computed from the date of birth and the date of the tests. Body weight was taken using an electronic weighing machine when boys were without shoes and wearing minimum clothes. Height was measured by an anthropometric rod. After taking height and weight, the peak oxygen uptake (peak VO₂) was measured by a treadmill test.

Peak oxygen uptake

The peak oxygen uptake (Peak VO₂) of the subjects was determined using a continuous graded treadmill exercise test, on a motorized treadmill (LE 6000, Erich Jaeger, Germany). All the subjects were instructed to avoid heavy food intake and exercise at least 2 hrs before the maximal treadmill exercise test in the laboratory. The detailed procedure of the test was explained to the subjects and a demonstration of the test was given to them. They were also asked to follow the instructions of the investigator during the experiment. The boys were first familiarized with treadmill running by allowing them to run
with the mouthpiece (with ‘Triple V’ volume transducer, dead space less than 50 ml). Following the practice period, the subjects were given time to rest, during which a 3-lead ECG configuration was applied in order to assess heart rate.

The testing protocol began with all subjects walking 4.0 km/h at 2% elevation for 1 minute. The speed was then increased by 1 km/h per minute till complete voluntary exhaustion, while the inclination was kept constant. Subjects were verbally encouraged to perform to maximal limits and the test was terminated when the subjects could not maintain performance with further increments in exercise intensity.

The main criterion for the attainment of the VO₂ max is a leveling off or plateau of VO₂ despite an increase in exercise intensity. Only a minority of children exhibit a true VO₂ plateau (Krahenbuhl et al., 1985). The appropriate term to use with children is peak VO₂, which represents the highest VO₂ elicited during an increase exercise test to exhaustion (Armstrong et al., 1991). Two of the three following criteria were followed for the establishment of peak VO₂ as a maximal index: a) failure of the VO₂ to increase more than 2.1 ml/kg/min despite a further increase in work load, b) respiratory exchange ratio (RER) greater than 1.0, c) maximal heart rate greater than the age predicted maximum heart rate ±5%. Additionally the appearance of signs of exhaustion, i.e., extreme forced ventilation, fatigue, facial flushing, dyspnea and unsteady gait were observed as subjective criteria of peak effort (Martinez and Haymes, 1992).

An integrated computerized analyzer (Oxycon Champion, Erich Jager, Germany) was used to measure expired air samples. Prior to each exercise test, the ‘Triple V’ volume transducer and gas analyzer were calibrated according to standard procedures (Volume & Gas calibration). The data from the gas analyzers and the volume transducer were preprocessed inside the Oxycon Champion and transmitted via an RS232 connection to a personal computer. The Oxycon software controls the system and peripheral equipment and organizes the data management. During the incremental exercise test, breath-by-breath data were collected and stored on an integrated computer system attached to the Oxycon Champion. The breath-by-breath data were then averaged over a 30-second sampling period and recorded. The rate of oxygen uptake (VO₂), rate of carbon dioxide production (VCO₂), respiratory exchange ratio (RER), pulmonary ventilation (VE) were monitored. The heart rate was also averaged over a 30-second period that was collected from 3 lead ECG systems and recorded. The ventilatory threshold (VT) was then determined from 30-second plots of VE/VO₂ and VE/VCO₂, and the heart rate was plotted against time.

The criteria used to determine the VT was a systematic rise in the VE/VO₂ as the VE/VCO₂ remains constant or decreases (Caizzo et al., 1982; Wasserman, 1984; Davis, 1985). The HR-time relationship obtained with the test was in part linear and in part curvilinear. The linear portion has been drawn by regression analysis and by subjective judgment; both techniques gave superimposable results (see results). The curvilinear part of the graph has been drawn by subjective judgment. The HRD was identified as the point where the heart rate response to graded exercise began to deflect from linearity by flattening (Conconi et al., 1982; Gaisl and Wiesspeiner, 1988). The VT and HRD were assessed independently by two researchers. When there were differences, the VT and HRD were again assessed independently by other researchers and common values among the two were considered. Figures 1 and 2 present the manner in which VT and HRD were determined respectively. The whole experiment was performed at room temperature varying from 23 to 25 degrees centigrade with the relative humidity varying between 50 and 60 percent.

**Data analysis**

The collected data were stored and analyzed for windows statistical software (SPSS for Windows, Version 6, 1993). A student ‘t’ test for paired observations was used to determine

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**Fig. 1** Representative plots of ventilatory threshold (VT) determination. VE, pulmonary ventilation; VO₂, oxygen consumption; VT, ventilatory threshold.
whether there was a significant difference between the mean \( \dot{V}_{O2} \) and related cardio-respiratory parameters measured at VT and HRD. Linear regression analysis was also performed to determine the relationship of \( \dot{V}_{O2} \) at VT with the \( \dot{V}_{O2} \) at HRD. The level of significance was set at less than or equal to 0.05 in each analysis.

**Results**

Table 1 represents the mean age, height, and weight of the boys. The peak cardio-respiratory responses to treadmill exercise of the boys are presented in Table 2. The mean peak \( \dot{V}_{O2} \), weight related peak \( \dot{V}_{O2} \), peak VE, and peak heart rate were found to be 1.75 l/min, 47.1 ml/kg/min, 66.9 l/min and 200.2 beats/min respectively.

Table 3 represents the peak cardio-respiratory response measured at the ventilatory threshold (VT) and HRD of the boys. No significant differences were noted between mean \( \dot{V}_{O2} \), weight related \( \dot{V}_{O2} \), pulmonary ventilation, heart rate and respiratory exchange ratio (RER) that was measured at VT and HRD. The \( \dot{V}_{O2} \) measured at VT and HRD was found to be 1.46 and 1.45 l/min, which was 84.0% and 83.1% of their respective peak values. Figure 3 represents the results of the linear regression analysis depicting the prediction of \( \dot{V}_{O2} \) (ml/kg/min) measured at VT from \( \dot{V}_{O2} \) (ml/kg/min) measured at HRD. A correlation of 0.94 \((p<0.01)\) was found between \( \dot{V}_{O2} \) at VT and the \( \dot{V}_{O2} \) at HRD.

**Discussion**

In the present study the mean peak \( \dot{V}_{O2} \) of the Bengali boys compares well with the value of another Indian study (Dey and Debray, 2002). However, the peak \( \dot{V}_{O2} \) of the boys was found to be lower than those reported of American and European boys (Krahenbuhl et al., 1985; Armstrong et al., 1991; Armstrong and Welsmen, 1994). These differences are, however, largely due to the difference in body size of the subjects. In the present study, the \( \dot{V}_{O2} \) measured at VT and
HRD was found to be about 83–84% of their peak values. These values of the present study are found to be higher as compared to the values observed in different studies (Rebrouck et al., 1985; Atomi et al., 1986; Mahon and Vaccaro, 1989; Mahon and Vaccaro, 1991). The cause of the high value of the subjects of the present study might be their higher physical activity or higher endurance activity. Thus, VO$_2$ measured at VT in the present study corroborates the findings of Bunc et al. (1986) and Bunc et al. (1987), where it was observed as about 82–85% VO$_2$ measured at VT of the young active boys. The boys of the present study were also active and had football and swimming training. It is well established that endurance training improves the cardiopulmonary responses at VT and HRD (Davis, 1985; Mahon and Vaccaro, 1989; Conconi et al., 1996; Fukuoka et al., 1997). Active children showed a higher cardio-respiratory endurance capacity, as assessed by the ventilatory threshold, compared to those who are less active (Weymans and Reybrouck, 1989).

Examination of data presented in Table 3 shows that there were no significant differences between mean VO$_2$, weight related VO$_2$, pulmonary ventilation, heart rate and respiratory exchange ratio (RER) that was measured at both VT and HRD. Figure 1 demonstrates that a high relationship ($r=0.94$) existed between VO$_2$ (ml/kg/min) measured at both VT and HRD. These results corroborate the study of Mahon and Vaccaro (1991). They reported no significant differences between mean VO$_2$, weight related VO$_2$ and heart rate that was measured at both VT and HRD. A correlation of 0.76 was found between the VO$_2$ (ml/kg/min) measured at VT and VO$_2$ (ml/kg/min) measured at HRD in a group of children 8 and 13 years of age. Baraldi et al. (1989) also showed a correlation of $r=0.80$ between the power output at VT and the power output at HRD in a group of children between 7 and 14 years of age.

The detailed comparison of the present findings with earlier studies is difficult since most of these studies assessed HRD and lactate threshold (LT). These studies used varieties of exercise protocols. For example, Conconi et al. (1982) used increasing running speed after a given distance to determine HRD and LT. Giasl and Wiesspeiner (1988) measured LT during graded exercise testing on a treadmill while HRD was assessed during a second test on a bicycle ergometer. Giasl and Hoffman (1990) proposed guidelines for determining HRD in children. They suggested that 12- to 16-minute exercise stages are necessary to accurately determine HRD. A protocol of increasing speed with increments of 0.5 km/h per minute was recommended when using a treadmill for exercise (Giasl and Hoffman, 1990). Mahon and Vaccaro (1991) used another protocol, which was claimed to be effective in determining the VT and HRD for children. They used a protocol of progressive speed increments up to 60–70% of a child’s VO$_2$max and thereafter the workload was increased by increasing the elevation every minute. In this protocol, the starting speed was 3.0 m/h at 0% elevation for 1 minute and speed was then increased by 0.5 m/h per minute until the individual attained his predetermined running speed. From this point on, the speed remained constant but the elevation increased by 2.5% every minute. This protocol used both a treadmill speed and inclination that was different from the Giasl and Hoffman (1990) protocol. Now measurements of HRD by the so-called Conconi test (Conconi et al., 1982) has also been modified. The increments of exercise intensity after a given distance indicated by a previous protocol have been substituted, in the
modified protocol, by a uniform time based on acceleration of exercise intensity. A protocol of starting speed 4–5 km/h with time-based acceleration of speed for children was recommended (Conconi et al., 1996). On the other hand, genetically Indian children are different in physique and endurance capacity as compared to their European, American, and African counterparts (Krahenbuhl et al., 1985; Chatterjee et al., 1992). So the exercise protocol used to measure endurance capacity including the ventilatory threshold needs standardization. Keeping all the views in mind, our study used a protocol of increasing speed with increments of 1 km/h per minute and a fixed 2% inclination. The starting walking speed was 4.0 km/h. The treadmill protocol used in the present study differed from the recommended Giasl and Hofman (1990) protocol for children and also from the protocol used by Mahon and Vaccaro (1991) with respect to starting speed, increment of speed, the use of elevation and the number of exercise stages. Nonetheless, the present study showed this protocol to be effective in determining VT and HRD in Indian children.

It may thus be concluded that no significant difference was found between the mean $\dot{V}O_2$ measured at VT and HRD. The linear regression analysis depicts the prediction of $\dot{V}O_2$ (ml/kg/min) measured at VT from $\dot{V}O_2$ (ml/kg/min) measured at HRD. The correlation between these two variables was $r=0.94$. It appears that HRD was an accurate predictor of VT in most boys, though not for all in the present study. So the validity of HRD to assess the ventilatory threshold in the determination of anaerobic threshold is uncertain, although there is a high degree of relationship between HRD and VT (ventilatory threshold).

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