

Presentation of the historical stages of the maximum aerobic speed of the child from 1938 to the presentday

عرض المراحل التاريخية للسرعة الهوائية القصوى لدى الطفل من عام 1938 إلى يومنا هذا

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Abstract:

The study of the maximum aerobic speed in children was largely inspired by the methods developed, from the eighteenth and nineteenth centuries, for adults. Since the remarkable work of Robinson (1938) and Astrand (1952) and work on cardiac output, nothing really new about the child's coping mechanisms for maximum exercise. Ethical and methodological constraints have hindered the development of maximum exercise physiology in children. However, in recent years the influence of maturation on VO2 max has been clarified. Genetic studies and the study of children in extreme conditions (training, altitude, etc.) are expanding and increasing.

Keyword: maximum aerobic speed, the child.

ملخص:

استلهمت دراسة السرعة الهوائية القصوى لدى الأطفال إلى حد كبير من الأساليب التي طوّرت للبالغين في القرنين الثامن عشر والتاسع عشر. ومنذ العمل الرائد لروبنسون (1938) وأستراند (1952) ودراسات التاج القلبي، لم يُكتشف جديد يُذكر حول آليات تكيف الطفل مع أقصى جهد بدني. وقد أعاقَت القيود الأخلاقية والمنهجية تطوير فهم فسيولوجيا أقصى جهد بدني لدى الأطفال. مع ذلك، في السنوات الأخيرة، اتضح تأثير النضج على الحد الأقصى لاستهلاك الأكسجين. وتشهد الدراسات الجينية ودراسة الأطفال في ظروف قاسية (كالتدريب والارتفاعات العالية وغيرها) توسعًا وتزايدًا ملحوظًا.

كلمات مفتاحية: السرعة الهوائية القصوى؛ الطفل.

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I - Introduction:

The energy required to perform a prolonged sub-maximum or maximum exercise depends essentially on aerobic metabolism. Cross-country (2000-3000 m) or cross-country (10 km in the Marathon) events require a particularly high aerobic capability. However, this aerobic capability is largely multi-factorial (Noakes, 1988). It has been shown that two subjects can have identical maximum oxygen consumption ($VO_2\text{max}$) but obtain very different chronometric performances, up to more than three minutes over a 10 km (Morgan et al., 1989). However, it turns out that in activities lasting about seven minutes, a high $VO_2\text{max}$ is a necessary condition, but not sufficient. For example, the mechanical efficiency that is how to spend energy during a trip (with equal amount of energy, is it a large or small consumer?) is a performance factor that must be considered.

- Aerobic fitness has three components :
- maximum aerobic speed (PMA) or ($VO_2\text{max}$).
- Endurance or aerobic capacity.
- Oxygen cost and mechanical efficiency.

Our study aims to expose the historical stages of maximum aerobic speed ($VO_2\text{max}$) during the biological development of the child, according to the work of Emmanuel Van Praagh, Eric Doré, Pascale Duché, Christophe Hautier and other researchers respectively;

1- Définitions

During a sub-maximum exercise, oxidative processes, objectified by oxygen consumption (VO_2), first increase gradually to an equilibrium value that is reached around the fourth minute. This delay is necessary for the gas exchange system to adapt and reach a level of operation compatible with the need for gas exchanges. From this point on, the energy required for resynthesis of ATP used for muscle contraction comes entirely from oxidative phosphorylations (Flandrois, 1992).

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The maximum oxygen consumption depends directly on the adaptation of the respiratory and circulatory gas exchange system responsible for capturing, transporting and delivering to the muscles the oxygen molecules necessary for oxidations. There is a linear relationship between developed power (watts) and oxygen consumption (VO_2 in $\text{l} \cdot \text{min}^{-1}$).

- However, the increase in VO_2 has a limit: from a variable given power according to the individuals, any new increase in the imposed power no longer determines an increase in VO_2 ; the maximum oxygen consumption is then reached ($\text{VO}_2 \text{ max}$) to which the maximum aerobic speed (PMA) corresponds" (Flandrois, 1992). Related to the body mass of the subject, VO_2 is called specific or functional ($\text{ml O}_2 \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$).

II -Methods and Tools

1-Presentation of current knowledge:

-Untrained child:

- $\text{VO}_2 \text{ max}$ and Growth:

Variations in $\text{VO}_2 \text{ max}$ as a function of growth have been published in several French (Grandmontagne, 1977; Flandrois et al., 1982, Guirauden et al., 1981; Mercier et al., 1986; Van Praagh et al., 1988) and foreign publications (Krahenbuhl et al. 1985;

Armstrong & Welsman, 1994; Léger, 1996; Rowland, 1996). From all these studies, it appears that:

- VO_2 absolute max ($\text{l} \cdot \text{min}^{-1}$) perfectly follows the growth curve of girls and boys. On the other hand, the variations are, at any age, more marked in the boy. Concretely this means that peak VO_2 also grows in children who are free of EPS or who have very reduced physical activity.

- $\text{VO}_2 \text{ max}$ specific ($\text{ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$) does not vary in boy between 6 and 16 years. On the other hand, this maximum oxygen consumption relative to body mass decreases from the age of 8-10 years in the girl. This sexual dimorphism is further accentuated at the time of puberty when the amount of

hemoglobin (O₂ transporter) is significantly lower and the amount of fat mass (estrogen) higher in the girl. In boys, androgens are responsible for an increase in muscle mass (high energy consumption). It turns out that in all long-term activities where it is a matter of carrying body mass, the boy is on average more efficient than the girl. Only when swimming long distances (e.g. crossing the English Channel) is the girl's slower body density an advantage.

2- What “normalization” factors to use?

The above discussion shows that it is classic and easier to compare subjects with different body dimensions by dividing peak VO₂ (l.min⁻¹) by total body mass (ml.kg⁻¹.min⁻¹). Especially since the correlation coefficients between these two variables are typically greater than $r = 0.70$ during growth (Davies et al., 1972). The data from the literature are consistent because they show that relative VO₂max is practically constant around 50 ml.kg⁻¹.min⁻¹ in boys between 8 and 18 years and decreases gradually during the same period in girls from about 45 to 35 ml.kg⁻¹.min⁻¹ (Krahenbuhl et al., 1985, Falgairette, 1989). Since the remarkable review written by Tanner in 1949, showing that the body mass normalization method could induce biases in the interpretation of the results, other statistical analyses were successively imposed (linear model (Williams et al., 1992) and allometric model (Astrand and Rodahl, 1970); McMiken, 1976; Bailey et al., 1978). Regarding the last model, the relationships between VO₂max (Y) and body dimensions (X) are described using an allometric relationship (or power function) (Nevill et al., 1992):

$$Y = a \cdot X^b \text{ ou } \log(Y) = a + b \cdot \log(X)$$

According to the theoretical dimensional analysis, in child peak VO₂ should be proportional to body mass at power 2/3 (Astrand and Rodahl, 1970). Most studies in children show an exponent of the order of 0,80. However, when we introduce in this model not only the mass, but also the size of the subject, the exponent is close to the theoretical exponent 0.67. Recently, Armstrong et al. (1999) using a multiplicative allometric model (Nevill et al., 1998) were able to show that when body dimensions are statistically well controlled, peak VO₂ continues to increase in boys during growth until adulthood. However, in the girl peak VO₂ increases until puberty, and then plateaus when it reaches the adult stage. Further studies will be needed, but already one can question the relevance of using total body mass as a common denominator in studies of aerobic performance

during development

III- Result:

1- VO2 max and maturation:

By studying the size growth of his son, from his birth until the age of 18, the Count of Montbeillard carried out the first longitudinal study in the world (1759-1777). Auxologists observe that as puberty approaches growth in height, weight and other somatic variables experience acceleration, peak, and then gradually decelerate into adulthood. The age of the growth rate peak is an important indicator for the exercise physiologist. This age is essentially individual, its knowledge allows to compare the results of physiological measurements between several individuals or groups. In a given population, the mean values of the peak growth rate are for girls between 12 and 13 years of age and for boys between 14 and 15 years of age (Tanner 1962, Sempé and Sempé 1971).

Given this «sexual dimorphism», the girl is biologically earlier and her body able earlier to «undergo» the different physiological and mechanical constraints imposed by the EPS sessions or by the training. There are only cultural «resistances» that make these biological principles not always respected. The class is by definition heterogeneous, this biological difference can group to 5 years between individuals of the same calendar age (Kemper and Van Praagh 1986). It goes without saying that the same typical PE session will not induce the same physiological response in a 13-year-old (actually having a biological age of 10 years) and another child (actually having a biological age of 15 years).

2- VO2 max and heredity:

Studies have been conducted on both twins and family composition to investigate a possible relationship between VO2 max and genetic potential (Malina & Bouchard, 1991). The identification parameter most used in these studies is the hereditary index (IH). This index means the proportion of total variance attributed to genotype and environmental variability. The index can vary between 0 and 1 (between 0 and 100%). Klissouras (1971) reported RH greater than 90%, however more recent studies show lower indices (Bouchard et al., 1986; Engström & Fischbein, 1977; Komi & Karlsson, 1979; Prud'homme et al.,

1984).

Bouchard & Lortie, 1984 set up an identical 5-month training performed by monozygotic twins (same genotype). This showed the existence of «good» responders (noticeable improvement of VO₂ max) and «bad» responders (stagnation of aerobic performance). According to the team of Bouchard (1986) 50 to 70% of the variance of VO₂ max can be explained by heredity.

In summary: It now seems well established that the variations of VO₂ max due to exercise are largely different from one subject to another. That the same training program induces different physiological responses according to the subjects. That the influence of genetic potential counts for much in the variations of this individual response.

3-Trained child:

3-1- VO₂ max and drive:

- The first studies:

The Swedish author Ekblom (1969) was the first longitudinal study in which 11-year-old boys underwent relatively intensive training for 3 years. Brown et al. (1972) conducted a similar study of girls aged 8 to 13. However, the duration of the training program is only three months. Kobayashi et al. (1978) then studied for five years the effects of varied and intensive training on boys aged 9 to 13. In this last study the authors used the growth rate peak, an important somatic marker showing that the effects due to training were significantly more marked after the onset of the peak

- Training parameters:

The improvement of VO₂ max through training depends on the duration, intensity and frequency of the sessions:

– Duration effects: A recent literature review of 27 longitudinal studies (Kemper and Knop, 1995) found that: Relative VO₂ max (ml.min⁻¹.kg⁻¹) of children and adolescents increased by an average of only 7,6% following workouts lasting less than 6 months. In long-term studies (6 months and more) there was even a decrease in relative VO₂ max (-1.8%). When the training criteria of the American

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College of Sports Medicine (1990) are met, the variations are virtually identical, whether they are pre-pubescent children (+ 10.7%) or adolescents (+ 11.0%). These values are close to those reported for adults.

– Effects of intensity:

Intensive training started in the pre- or peripubertal period or in the adult stage does not increase VO_2 relative max ($\text{ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$). Some studies (6 out of 9 in total) show that the maximum aerobic speed improves during the pre-pubescent stage, when the training regime is equivalent to that observed in adults. The same observation was made on more mature subjects (adolescents). Lacour and Denis (1984) report a study by Flandrois et al. (1979), the latter observed a 40% improvement in VO_2max ($\text{l} \cdot \text{min}^{-1}$) in young athletes aged 15-16 years subjected to daily and intensive training of 6 months.

- Effects of frequency: Duché (1992) summarized studies that observed a change (%) in VO_2 max based on the number of training hours per week.

In summary, these studies show:

- it doesn't seem necessary to start VO_2 max training too early. A good indicator could be the peak of maximum growth which in the French population is on average for the girl at 12 years and 14 years for the boy.

- that VO_2 max is limited by individual genetic potential.

- that its improvement is only possible if the training has a level of intensity that is not necessarily compatible with the average ability of a college class.

3-2- VO_2 max and decompression:

The almost complete cessation of the regular practice of APS or regular sports training and its influence on VO_2max has been very little studied in children. However, Klausen et al., 1981 showed in a group of adolescents that the gain of about 15% obtained through more intensive training for 2 months, had completely disappeared after 8 weeks of inactivity. In France, Flandrois et al. (1982) showed that VO_2 max was reduced by 5% in boys and 9% in girls after three months of training due to school holidays (swimmers from 11 to 16 years). Figure 8 shows that these phenomena were observed two years in a row,

which significantly reduces the share of chance.

-Rowland (1994) measured VO₂ max in five children aged 7-11 years immobilized for 10 weeks after an accidental femur fracture. After 3 months of re-training, VO₂ max was 37, 2 to 42, 9 ml.kg⁻¹.min⁻¹ (more than 13%). After these three months, VO₂ max no longer increased. The author hypothesized that the 13% increase during the rehabilitation period, actually corresponds to the decrease due to immobilization in bed. These studies, although they do not allow to conclude, could be a subject of reflection for those in charge of the thorny file: school rhythms (alternating EPS-holidays). Remember that we still hold in France the world records: a) the longest school day, b) the longest school holidays. Moreover, they tend to demonstrate the extreme plasticity of our physiological functions provided that they are sufficiently stimulated.

3-3-VO₂ max concept:

In adults, the maximum consumption of oxygen is an indisputable indicator of the good or bad functioning of the cardio-respiratory system, as well as an essential performance criterion in endurance tests. However, it is not at all certain that the results obtained in children can be interpreted in a similar way. Since specific VO₂ max (ml.min⁻¹.kg⁻¹) of the child practically does not vary during growth, while at the same time its endurance can very significantly improve. This gain can be obtained by a decrease in energy cost (the subject becomes more economical) during some prolonged exercises, either by qualitative changes in energy release, or by the improvement of anaerobic factors (speed, strength).

3-4- Speed concept associated with VO₂ max (VAM):

VO₂ max is a useful parameter for comparing the maximum ability of subjects to consume O₂ during a given exercise. However, it is not of direct practical use. It is necessary to better know at what maximum speed this parameter corresponds (Margaria et al., 1965). Moreover, this index not only takes into account VO₂ max, but also the mechanical performance with which each subject performs a given exercise. After determining VO₂ max on the treadmill, Astrand (1952) ran girls and boys 4 to 18 years of age (Table 2) for 5 min at the speed at which VO₂ max was obtained ("maximum aerobic speed" (VAM in km.h⁻¹). In boys there is undoubtedly an effect of age, which is not the case in girls. The 10-year-old

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girl runs almost at the same VAM and for five minutes as the 15-year-old.

3-5 -Evolution of VAM(km.h-1) for girls and boys by age(Astrand, 1952):

Recently, Berthoin (1994) evaluated VAM on a large sample of girls and boys aged 12 to 17 using a field test (Léger & Boucher, 1980). As in the Astrand (1952) study, VAM increased significantly with age in boys (from 12 to 13.7 km.h⁻¹ between 13 and 15 years, respectively) and was independent of age in girls (from 10, 8 to 10, 8 km.h⁻¹ between 12 and 17 years, respectively). It should be noted that the VAM values in the laboratory (on treadmill) are significantly higher than those in the field (subject driven by the engine, absence of aerodynamic forces). The maintenance time of the VAM in this school population is substantially identical (just over 5 min) to that observed in the study of Astrand (1952).

3-6- VO2 max or Endurance?

It is often about the endurance qualities of African runners, and especially Kenyans. Should these runners from the highlands have exceptional VO₂ max? Saltin et al. (1995) studied the best Kenyan runners (cadets-juniors-seniors) to test their aerobic potential. Sub-maximum and maximum tests were performed on the treadmill, both at sea level and at high altitude (2000 m) and a comparison was made with a group of young Kenyan boys not trained and the best Scandinavian runners. In altitude, the untrained and trained boys have respectively a VO₂max of 47 and 62 ml.kg⁻¹.min⁻¹. Seniors had a VO₂ max of 68 ml.kg⁻¹.min⁻¹ on average, at altitude and 79.9 ml.kg⁻¹.min⁻¹ at sea level. That is, practically the same values as the best Scandinavian riders. In contrast, race economy (VO₂ at a given speed) was significantly better (VO₂ lower) among Kenyans. The authors conclude that a combination of skills, daily physical activity at altitude (running = means of transport) and very intensive training, can explain the good results of these runners.

3-7- Future research directions:

Questions that have not yet been answered include:

- Why is the adaptation to VO₂ max training less in children than in adults?
- What levels of intensity, duration and number of sessions are required to improve the child's VO₂max?

- Can an increase in daily physical activity (e.g. more EPS sessions) influence VO₂ max?
- Is puberty a particularly sensitive time?
- Work simulators (ergometers) are rarely adapted to the biological possibilities of the child.
- New and non-invasive technologies (MRI, NMR spectroscopy...) will undoubtedly give a new era to the knowledge (at the cellular and molecular level) of child adaptation during maximum exercise.

IV - Conclusion:

The study of the maximum aerobic speed in children was largely inspired by the methods developed, from the eighteenth and nineteenth centuries, for adults. If the first study (1926) of the child's gas exchange was carried out under sub-maximum conditions, it was not until 1938 that the first study of VO₂ max was born. Since the remarkable work of Robinson (1938) and Astrand (1952) and work on cardiac output, nothing really new about the child's coping mechanisms for maximum exercise. Ethical and methodological constraints have hindered the development of maximum exercise physiology in children. However, in recent years the influence of maturation on VO₂ max has been clarified. Genetic studies and the study of children in extreme conditions (training, altitude, etc.) are expanding and increasing. However, pediatric ergometry is waiting for the development of a non-invasive technology, but still extremely expensive, to really examine aerobic metabolism at the cellular level.

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