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ABSTRACT

This is a report on research in the field of physical responses of children to strenuous activity. The paper is divided into three subtopics: (1) peak performance measure in children; (2) training effects on children; and (3) importance of physical activity for children. Measurements used are oxygen consumption, ventilation, heart rate, cardiac output, and work rate. Children between the ages of 6 and 13 are the subjects. Conclusions indicate that strenuous physical activity has beneficial effects in the physiological development of the child, which apparently carries over into adulthood and that physical activity is needed for normal growth and development. However, consideration should be given to the possibility of stress fractures and related bone disorders that may occur in children especially during a growth spurt. Suggestions are given on the best ways to provide healthful exercise for children. (JD)

Physiological Response to Physical Activity in Children

by

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The assessment of peak physical performance measures in young children is becoming increasingly important with the proliferation of youth sports programs in the United States. With over 22 million participants, there is a real need to know with respect to the following questions:

1. Do peak performance measures differ between age groups?

2. Are children trainable? If yes, are there specific ages as to when they become trainable?

3. Does their trainability vary between aerobic (low intensity, long duration) and aerobic (high intensity, short duration) types of physical activity?

4. What are the physiological beneficial and/or detrimental effects from participation in physical activity?

The paper is divided into three subtopics which should provide us with the answers to the above questions: 1) Peak performance measures in children, 2) Training effects on children and 3) Importance of physical activity for children.

Before I begin, I would like to quickly review a few of the physiological terms which will be discussed. The physiological measure that is regarded as most indicative of endurance (aerobic) capacity is maximum oxygen consumption (max $\dot{V}O_2$). In physiologic terms this is defined as the maximum rate of oxygen utilization during intense work. Max VO_2 is usually measured in liters of oxygen per minute (l/min), but it is also expressed by body weight (BW) and lean body weight (LBW), as well. Another physiological effect studied is cardiac output (Q) which is defined as the volume of blood pumped by the heart per minute (l/min). Static dimensions such as size of the heart (volume), blood hemoglobin (Hb) concentration and lung volume also have been used to measure physiological efficiency.

The use of muscle biopsies has proven useful in order to determine the effects of training on muscle tissue. By studying the biochemical and/or histochemical make-up of a muscle, one can determine if the muscle has increased its potential to perform aerobically or anaerobically. Anaerobic (glycolytic) work is high-intensity, short-duration activity, such as the 100-yard dash, swinging a golf club or serving a tennis ball. Aerobic (oxidative) work is high-intensity, long-duration activity such as the one-mile run or cross country skiing. Enzymes such as (SDH), and (DPNH-diaphorase) are indicative of oxidative potential. Conversely, (PFK), a rate limiting step in glycolytic activity, and lactate concentrations are measures of anaerobic potential.

1. Peak Performance Measures.

The first area of discussion will center on peak physical performance measures such as oxygen consumption, ventilation, heart rate, cardiac output and work rate in children. There appears to be a considerable volume of literature concerning physical performance measures in children between the ages of 11-15 years. Literature pertaining to children less than 11 years of age is practically non-existent, particularly comparative studies between age groups.

In a recent study from our laboratory, peak performance measures were assessed in three groups of children; 6 to 8 years, 9 to 10 years, and 11 to 13 years. Even though the ages ranged from 6 to 13 for this study, it should be noted that only two 6 year old and two 13 year old children were tested. The mean heights and weights for each group were similar to the results reported in earlier studies, shows that the mean heights and weights for each group were significantly ($P < .05$) different from each other.

The performance measures included oxygen consumption (l/min and ml/kg body wt/min), respiratory quotient, ventilation, cardiac output, stroke volume, (vol blood/beat), workrate, and heart rate. We have chosen to refer to the highest obtained performance scores for each variable as a "peak" value as opposed to a "maximal" value. The rationale for this is based on the difficulty to obtain true maximal values on the bike in younger children due to such factors as general discomfort, nervousness, and deficient leg strength at the higher frictional resistances.

No significant difference existed between the three groups for peak heart rate. The mean peak heart rate for each group was about 193 b/min with a peak heart rate recorded for the younger, middle and older groups of 198, 204 and 210 b/min, respectively. The mean peak heart rates for the three groups in this study were slightly lower than those reported by Skinner and Astrand who also reported no statistical differences in mean peak heart rates between similar age groups. It should be pointed out that both Skinner and Astrand used the treadmill when collecting their work performance data which may account for the differences in peak heart rates between this study and their studies. Statistical differences existed between groups for ventilation or volume of air consumed/min. The older children had significantly higher ventilation values when compared to the younger children. The mean peak ventilation values were 50.8, 58.1, and 62.3 l/min for the younger, middle and older groups, respectively. Wilmore reported similar data for 7 to 13 year old girls. That is, ventilation increased with age from 57.7 l/min to 70.1 l/min for the youngest and oldest children, respectively.

Significant increases in peak ventilation with age is not surprising since several studies have reported increases in lung volume with age and body dimension which would account for these increases.

Mean peak workrate values on the bike also differed significantly (P $<$ .05) between groups. The older children always did significantly more work.

Respiratory quotient, cardiac output, stroke volume, (vol/beat), arterio-venous O_2 difference did not significantly differ between the three groups. The mean peak respiratory quotient varied by .02 between groups with .92 recorded for the younger and middle groups and .94 for the older group. Peak cardiac output increased with age but not significantly. The younger group averaged 11.4 l/min while the older group averaged 13.1 l/min with 12.0 l/min for the middle group of children. Stroke volume also showed a similar increase with age. That is, the younger, middle and older age groups had mean peak stroke volume of 59.2, 61.4, and 67.9 ml/beat, respectively. A similar pattern of increase with age also existed with arterio-venous O_2 difference.

The indirect (CO_2) Fick method for calculating cardiac output in young children has been shown to give very reasonable results when compared to results obtained via the direct Fick method. Our data for cardiac output, stroke volume, and arterio-venous O_2 differences for the 10-13 year old children compares favorably with results from other studies utilizing both the direct and indirect Fick method. When comparing the Q, SV and a-v O_2 differences results to data reported for young adults, the Q and SV values are lower and the a-v O_2 difference was larger for our study. One contributing factor for these differences may be due to the absolute amount of blood distributed to different tissues or organs which is less in persons still growing as compared to adults of larger body dimensions. It should be noted when compensating for body size, Q and SV values for children are very similar to young adults.

Significant differences ($P < .05$) were obtained for peak oxygen consumption measured in l/min, between groups. However, when oxygen consumption was expressed in ml/kg body wt/min, there were no significant differences. The mean peak oxygen consumption values for the younger group was 1.28 l/min which increased to 1.84 l/min for the older group. The results also show that the peak oxygen consumption values (l/min) were significantly ($P < .05$) different between each group. That is, the middle group was significantly higher than the younger group but significantly lower than the older group.

The mean peak oxygen consumption ($\dot{V}O_2$) values for the 6 to 8 and 9 to 10 year old age groups are similar to peak $\dot{V}O_2$ values for the same age groups reported by Skinner and Astrand. However, the mean peak $\dot{V}O_2$ values for the 11 to 13 year old group is slightly greater (.3 l/min) than the data reported by Skinner. When considering peak oxygen consumption as measured by liters per minute it appears that as chronological age increases from 6 to 13, children have a greater ability to consume more oxygen. This difference between age groups does not exist when body weight is taken into consideration. Our data showed a decrease in peak $\dot{V}O_2$ (ml/kg body wt/min) for the two older groups when compared to the 6 to 8 year old group. Skinner reported a "leveling off" of peak $\dot{V}O_2$ when expressed as ml/kg body wt after the age of 7. Astrand reported a significant increase in peak $\dot{V}O_2$ (ml/kg body wt) from ages 6 to 8 for both sexes and a "leveling off" from age 8 to 14 for boys and a decrease for girls.

It is apparent from these data and those reported by other, that certain performance measures will increase with age or maturation. These variables are oxygen consumption (l/min), ventilation (l/min), and work rate (kpm/min). Other peak measures such as cardiac output, heart rate and respiratory quotient are not affected by the maturation, at least not up through the age of 12. That is these measurements do not differ statistically between age groups.

2. Training Effects on Children.

The question now arises to the probability of increasing even further through training those measures already positively affected by maturation. Additionally, will training alter the upper limits of those peak values not affected by maturation. Schmücker reported that changes in peak oxygen consumption other than those related to normal growth and development could not be expected until the age of 12. This leads up to the second area of discussion which deals with the trainability of children.

The first parameter of concern is oxygen consumption. The literature on training of young shows that only Ekblom used control subjects throughout the entire study. Without control subjects it is very difficult to assess any real training effect since we already know that an increase in peak oxygen consumption can be expected through the maturation process. Ekblom's study can be divided into 2 studies - one lasting 6 months and the other 32 months. In the first part he dealth with 6 experimental (training) and 7 control boys, 11 years of age. The pre-training height and weight for both groups were similar. The peak $\dot{V}O_2$ (l/min) value for the control group increased from 2.01 l/min to 2.07 l/min or 3% after 6 months, whereas the training group increased from 2.15 l/min to 2.48 l/min or 15% when the study was extended to 32 months. One experimental subject and 3 control subjects dropped out this reducing the sample size to 5 and 4 for training and control respectively. The peak $\dot{V}O_2$ for the control group increased 37% or from 1.85 l/min to 2.54 l/min as compared to the training group which increased 55% or from 2.22 l/min to 3.45 l/min. The training consisted of interval running, sprint training, distance training, strength.

Like that of peak $\dot{V}O_2$, Ekblom showed an 18% increase in ventilation for the training group (68.0 l/min to 80.4 l/min) as compared to a 13% increase for the control group (72.3 l/min to 81.8 l/min) after 6 months of training. Following 32 months of training, the training group increased from 70.0 l/min to 111.0 l/min or 58% whereas the control group demonstrated a 41% increase (65.7 to 93.0 l/min).

Heart volume was determined via x-rays taken with the subject in the lying position. Ekblom reported very little difference in change between the training group and control group. In fact, the control group showed a 7% increase as compared to the training group's 5% increase, after 6 months training. Following 32 months of training, the control group showed a heart increase from 475 to 580 ml (37%), whereas the training group increased from 480 to 710 ml (48%). Eriksson reported a 10% increase as well as Dubelin. However, once again there were no controls for comparative purposes.

Another area of concern deals with the adaptation of skeletal muscle in children to training.

2a. Fiber Composition and Enzyme Activity in Skeletal Muscle.

From results of earlier studies by Eriksson, it appears that local adaptations occur in the skeletal muscle of boys 11-15 years of age as a result of training. Most of the changes are similar to those reported for adults, but some differences are specific to boys of this age. A search of the literature revealed that no data on fiber composition and enzyme activity are available on boys under the age of 11 years or for girls of any age.

Biopsies of the vastus lateralis in five 11 year old boys revealed a muscle composition of 55 percent slow twitch and 45 percent fast twitch fibers before training, with no significant change following 6 weeks of training, on the bicycle ergometer. However, changes in the oxidative aerobic and glycolytic anaerobic potential of children's muscle fibers were reported in another study by Eriksson. SDH (aerobic) activity was reported at 5.4 mol/(g x min) before training and was increased to 7.0 mol/(g x min) following training. It should be noted that the SDH activity found in boys was greater than in most sedentary adults. (DPNH-diaphorase) staining, which is also indicative of oxidative capacity and also mitochrondrial density, was more pronounced following the training period. Both SDH activity and DPNH-diaphorase staining are indicators of aerobic potential. Thus, it appears that the training program had a positive effect on the aerobic capacity of 11-13 year old boys.

The PFK (anaerobic) activity of children has been reported to be 40-50 percent of that usually found in adults. Also, when compared to adults, children have lower muscle lactate concentrations and oxygen deficits. These data help to explain why children have a relatively low anaerobic capability. However, training does have a positive effect on these variables in that a 75-80 percent increase in PFK activity and significant ($P < .05$) increases in muscle lactate concentration and oxygen deficit (1) have been reported. It should be noted that even after training, the PFK activity of children was still less than that of adults. Training also brought about increases in the resting levels of the high energy compounds of adenosine triphosphate (ATP) and creatine phosphate (CP).

D. Importance of Physical Activity for Children.

It has been hypothesized that physically active prepubertal children will have greater physiological upper limits (i.e., max VO_2) as adults because of their involvement in strenuous activity programs during their growing years. The rationale for this hypothesis is based on some indications that growth hormone plays an important role in hypertrophy of the heart and other organs after exercise. During growth and physical activity, there is an elevated concentration of growth hormone in the blood. Thus, it is likely that the rate of growth can be accelerated by physical training during puberty when the individual is sensitive to the action of growth hormone. It is felt that as a result of exercise, static dimensions such as lung volume, heart volume, and height will increase more than expected. These resultant changes would have a positive effect on the overall development of the physiological upper limits, when children become adults. Further research in this area is needed to clarify the relationship between activity, growth and functional capacity in young performers.

There is abundant research evidence to suggest that physical activity is essential for the harmonious development of children. However, will strenuous physical training have any deleterious effects on the growing child? One longitudinal study investigated the effects of very intense physical training on static dimensions (i.e., heart and lung volume) of thirty top girl swimmers ages 12 to 16 years. Positive changes were reported in the oxygen transport system. That is, not only did max VO_2 increase but vital capacity, total Hb and heart volume also increased. From the data reported, there was no indication that hard physical training had caused any negative effects on the growth of the organs involved in the oxygen transport system. However, the author noted that any one of the above measures taken by itself could be construed as abnormal development (i.e., an enlarged heart). The thirty young girl swimmers were studies for a total of 10 years. By the end of the investigation, all of the girls had stopped their regular training and had adopted a sedentary lifestyle. Due to this inactivity, the girls showed a pronounced decrease in their aerobic power (29 percent). However, the dimentions of the lungs and heart were relatively unchanged.

Other studies also have reported larger heart volumes in retired top athletes who formerly participated in endurance type sports. Thus, at present it appears that no deleterious effects of strenuous activity have been demonstrated on certain static dimensions for adults who participated in athletic competition at younger ages.

<u>Summary</u>

Even though a paucity of literature exists concerning the trainability of children, it does <u>appear</u> that children beginning as early as age 10 can enhance their aerobic (endurance) capabilities through endurance type of training. Data for children less than the age of 10 are not available. One can only speculate as to what might occur even though one researcher has stated that children aren't trainable until after the age of 12.

Data by Eriksson show that boys, 11 years of age increased their ability to perform anaerobically through training but not to the extent as achieved through aerobic work. In fact, Eriksson showed that aerobically, children have the same potential as adults when compensating for body size. However, this was not true for their anaerobic potential, which is probably due to a lower rate of activity for the enzyme phosphofructose kinase (PFK) which is a rate limiting enzyme in anaerobic metabolism. Apparently this difference disappears during adolescence.

It does appear that strenuous physical activity has beneficial effects in the physiological development of the child. This benefit apparently carries over into adulthood. However, one should be cautioned about the possibility of stress fractures and related bone disorders which may occur in children through strenuous, repetitive types of physical activity especially during a growth spurt.

Lastly, I certainly support the contention that physical activity is <u>needed</u> for normal growth and development. In dealing with children in competitive sports where some sort of physical training takes place,

2

we must remember that we are dealing with children.

Therefore, the following suggestions may be helpful:

1. Provide them with frequent rest periods.

2. Be sensitive to their individual needs. If a child is in a growth spurt, he/she will tire more easily.

3. Don't abuse the fat child. It is important for them to be involved in physical activity. Encourage them don't discourage them.

4. Be sensitive to the environment. Provide children with the proper liquids, especially on hot, humid days. Remember that fat children are less tolerant of the heat. Therefore, they may need more rest and fluids than usual in order to prevent heat disorders.

5. Remember that if a child is poorly skilled, it may be due to his/her late maturation. Once again, it is important that we don't turn these children off to physical activity. Be patient and give the child a chance to develop.