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ABSTRACT

Exercise is generally held to be a significant factor in the growth, development, and health of children and adolescents. The effects of physical activity regimens on general growth, as well as quantitative and qualitative changes, in animal muscle and bone tissue have been clearly demonstrated. Less is known about the role of exercise and related metabolic factors in influencing morphological and functional changes in children. The significance of physical activity in controlling body weight and maintaining a healthy balance among the tissue components of growing children has been repeatedly demonstrated. Similarly, research has shown the positive effects of vigorous exercise regimens on muscular strength, muscular endurance, and physical working capacity of children. Recent research points to a complex interaction of neural, hormonal, and metabolic factors in response to the stresses imposed by exercise--the effect on tissue and organ growth being a reflection of the nature, duration, and intensity of the exercise regimen as well as the maturational level and exercise tolerance of children. That certain, as yet underfined, levels of physical activity are essential to the normal growth and health of children would seem to be self-evident. Based on present knowledge, these levels will vary with the nature of the physical activity program and the functional capacity and maturational level of the child. (Author/PB)

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Effects of Exercise on Children*

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Our profession rests on the premise that exercise when conducted under the proper conditions contributes significantly to the health, growth, and development of children. Yet, when we are asked just what are the effects of exercise or physical activity programs on the physical and psychological well being of children many are hard pressed for convincing answers, particularly if we are asked for evidence to support our claims. What, then, does research tell us about the effects of exercise on children?

Under the supposition that you are primarily interested in the effects of protracted exercise regimens on children I will confine my remarks almost exclusively to this end. Hence, my comments will be directed to what research tells us about the effects of regimens of physical activity on general body growth, growth of certain body tissues (muscle, bone, and fat), muscle strength, physical working capacity, and social-psychological development. Since well controlled longitudinal investigations in which exercise has served as the experimental variable are limited, it will be necessary occasionally to draw inferences from studies on animals.

General Body Growth. What, then, are the effects of protracted exercise regimens on general body growth? Studies on young laboratory animals (rats) have shown that the animals given the freedom to exercise grow faster than confined littermates (Ring, et al. 1970). On the other hand, the evidence points to a retardation in general body growth of rats strenuously exercised, a lag proportionate to the severity of exercise (Bloor et al. 1970). In

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other words, beyond some undefined optimum, extremely severe exercise unfavorably affects growth.

The early research of Donaldson and Meeser (1931) who exercised albino rats in a revolving cage an average of 5 miles per day for 170 days showed that the exercise had a favorable effect on tissue and organ growth, primarily an accumulation of muscle tissue and loss of fat. There were substantial gains during the periods of exercise, but with ensuing inactivity there was regression to "normal," the regression being a function of the length of the period of inactivity.

Only limited research has been done to date on the effects of physical activity programs on body growth of humans. The research of Ekblom (1969) in Stockholm in which the stature of a group of five eleven year old boys exposed to 32 months of physical training (two and three times weekly) was compared to the stature of seven non-trained controls before and after the experimental period. The results showed that in comparison to the control group and to normative data on healthy Swedish children, the exercised boys as a group made only slightly greater gains in height. These findings are in line with the early study of Schwartz et al. (1928), but are not consistent with the research of Parizkova (1968) who found no difference in growth in stature of physically active and physically inactive Czech boys under observation from ages 11 to 15 years. Simon (1962), in a 6 month study in which diet, study time, recreation, and sleep were controlled, reported only slightly greater gains in stature of 14 and 15 year old trained and untrained Polish males (average gains of 1.19 and 1.10 cm., respectively). On the other hand, the six months training program (six times weekly of gymnastics, track, field athletics and games) resulted not only in greater physical performance gains in the trained males, but the difference in gains in girth and breadth measures clearly favored the exercise group.

The growth promoting effects of gymnastics upon girth measurements during the growing years has been well established for over 50 years (Godin, 1920). That the training effects on muscularity are transitory and reversible, at least in later adolescence, has been clearly demonstrated (Tanner, 1952).

It is evident that physical activity per se is of little consequence in affecting growth in stature, although its impact on muscularity is significant. There is, however, little to support the belief that permanent alterations in physique result from exercise during the growing years. On the other hand, there is evidence (Steinhaus, 1933) to indicate that muscle bulk is more easily added to the frame of a child or adolescent of mesomorphic than one of ectomorphic build.

Perhaps the most complete investigation is that of Astrand et al. (1963) in which extensive physiological and growth data were obtained on some thirty girl swimmers, ages twelve to sixteen years who had engaged in highly competitive swimming for a period of several years. The majority had begun heavy training before thirteen years of age, the earliest at ten and the latest at fifteen years. The girls had learned to swim at an average age of 5.8 years (range of 5 - 8 years). The girls were highly selective representing the best of approximately one thousand aspirants. The severity of the training program varied considerably among subjects, the total distance covered per week ranging from 6,000 - 65,000 meters and the number of hours from six to twenty-eight. Longitudinal growth data on these girls initially taken at seven years of age showed that as a group their increase in height became somewhat more marked in the later years (the training years) although the exaggerated gain could not be directly attributed to the training program. The investigators report that no harmful effects have been noted in any of the swimmers up to this time (two years subsequent to the investigation). A second part of this study entailed a questionnaire which was given to the eight-four women finalists in the Swedish swimming championships in the period 1946-55. The swimmers as a group some six to fifteen years after the competitive years were healthy and socially and psychologically well adjusted. More than three out of four were married and two-thirds had children. As a group they had a positive attitude toward swimming, although many questioned the advisability of present strenuous training programs and some considered it to be detrimental.

Muscle Tissue. Clearly the most dramatic effects of extended periods of vigorous physical activity are on muscle tissue. It has long been recognized that muscle cells undergo hypertrophy as a result of training, the magnitude of the increments being a reflection of the intensity and duration of the taining program. The stimulus for hypertrophy is believed to be due largely to the tension developed by the exercising muscle, since it has been demonstrated that a muscle with normal nerve and blood supply will atrophy under conditions of disuse or of tenotomy. The overload of a muscle apparently alters the permeability characteristics of the sarcolemma providing greater accessability of amino acids which in turn favors protein synthesis (Edgerton, 1973).

The critical question during the growing years relates to the growth stimulating effects of exercise as differentiated from the increases in muscle size due primarily to the growth hormone or to androgens. Testosterone is recognized as a potent force in muscular protein synthesis operating through control mechanisms activated by DNA and RNA (Edgerton, 1973). While growth hormone, like the androgens, has a powerful anabolic effect on muscle tissue, it should be realized that muscular hypertrophy induced by overloading muscles can be produced in hypophysectomized animals (Goldberg, 1969). Thus, it would seem that the growth hormone and exercise function independently in affecting the mechanisms that control muscle growth. Exercise may, however, affect muscle growth indirectly through the growth hormone, for it has been shown that vigorous physical activity brings about increased levels of plasma growth hormone, a result of temporary hypoglycemia resulting from exercise itself (Hunter and Greemwood, 1964). Elevated levels of growth hormone in blood plasma have been noted after approximately one hour of exercise, the level dropping rapidly with oral glucose administration.

It is clear that in addition to the above there are neural factors at work in normal muscle growth and in muscle hypertrophy, in part a reflection of the involvement of neurons in the use of muscles and in part attributable to the control that motoneurons exert on enzymes and substrates in muscles. The specific mechanisms that control muscle growth are not as yet fully understood, but it is clear that the contractility, protein synthesizing capabilities, and energy releasing mechanism within the muscle respond positively to chronic overload.

While it is clear that certain minima of chronic overload are necessary to stimulate muscle growth, the intensity and duration of the exercise necessary for optimum growth of the child have not been ascertained and probably never will. This can, I believe, be safely stated, for who is to say exactly what the optimum muscular development should be for a given child and even if one were so bold as to propose it, how would one with any degree of exactness solve the problem of individual differences? There is, however, sufficient information on exercise and muscle growth to provide us with general guidelines in designing physical activity programs if our purpose is to favorably affect general growth and muscular development without overdoing it.

Adipose Tissue. One of the most striking effects of vigorous activity during the growing years is its effect upon the child's body composition, that is the relative amounts of lean, fat free body mass and depot fat. In infancy adipose tissue constitutes a much larger percentage of body mass than it does once walking takes place. Shirley (1933) in her research on locomotion in infancy, reports a rapid drop in weight/height ratios once walking begins. While not a great deal is known about obesity in infancy and early childhood, the research of Heald and Hollander (1965) showed that at one year of age girls destined to become obese in adolescence were at this early age substantially heavier per unit of body length than those destined to be of normal weight. Mullins (1959) holds that obese adults come from one of two groups, namely those whose obesity is of juvenile onset (childhood or early adolescence) or those who developed obesity after puberty. According to this investigator approximately 75 - 80% of juvenile obesity continues into adulthood.

A critical factor in childhood obesity, which bodes ill for the future, is that its early onset is likely to be characterized by an increase in adipose cell number. The research of Hirsch and Knittle (1970) provides rather convincing evidence that increases in fat cell number result primarily from stimuli operating early in life. Exactly what these stimuli are, nutritional, endocrine, behavioral, or genetic, have not as yet been clearly identified. The significance of physical inactivity in childhood obesity (of other than metabolic origin) is now generally recognized. The work of Mayer and his colleagues (1963) on obesity in early adolescent boys and girls in the Boston area has provided convincing evidence of this. The implication is clear, namely that the seeds of obesity are sown early in life.

The longitudinal studies of Parizkova (1968) in Prague have clearly shown that boys involved in a vigorous and regular physical activity program, as comapred to inactive boys, substantially increased their lean body mass at the expense of fat. Paralleling the change in soft tissue development, there was a change in prc .tionality of the skeleton in the physically active boys --- relati / narrower hips in relationship to height and bi-acromial breadth. ·ne more vigorous the program the greater were the changes.

The positive effects upon body composition, weight loss, and physiological work efficiency, of treating obese boys and girls through a program of controlled diet and exercise has also been demonstrated by Parizkova, et al. (1971). In view of the greater difficulty that occurred in altering body composition after puberty than before, these investigators recommend that prevention and diagnosis of initial stages of obesity should come at an early age.

Bone Growth. The precise effects of physical activity on bone growth in humans is difficult to assess. It is well known that physical inactivity, such as prolonged bed rest, leads to decalcification of bone tissue. That tensile and compressive force is a stimulus for bone growth is generally recognized (Evans, 1957). Within the limits of tolerance, pressure or tension leads to the formation of new bone, but if the pressure is extreme there is a destruction of bone by resorption (Weimann and Sicher, 1955). The effects of heavy physical activity in enhancing appositional growth of long bone has been well established (Buskirk, 1955). On the other hand, the effects of long and frequently repeated compressive force on endochondral bone has been shown to be damaging (Evans, 1957). As with all tissues in the body there is a tolerance limit (intensity-duration) beyond which the stressor agent must not go. This is particularly true at the epiphysieal plate where continued heavy pressure can result in permanent damage. What, then, of the excessive pounding which may occur in long distance runs now engaged in by pubescent boys and girls? There is, however, general agreement that moderate stress in the form of vigorous exercise is a positive force in building sturdy bones.

Strength. As children advance in age they become bigger and stronger. That muscular strength and power in boys and girls increase relatively more rapidly than changes in body size has been clearly established (Asmussen and Heebøll-Nielson, 1955). The reason for the disproportionate increases in strength is believed by Asmussen and Heebøll-Nielson to be due to central nervous system maturation and to improved neuromuscular coordination.

Unfortunately we have very limited data from longitudinal studies on growth in muscular strength in children and none from investigations in which exercise has been systematically controlled over a period of years. In fact, little is known about the differences in gains in either static or dynamic strength of physically active children in comparison to sedentary controls. We do know, however, that it is impossible to predict with accuracy the strength changes that will occur in children during either childhood or adolescence (Rarick and Smoll, 1967).

Within limits we have some basis for accounting for individual differences in strength among children. Data from cross-sectional studies show that boys of mesomorphic build are stronger (isometric strength) per unit of weight than boys of either endomorphic or ectomorphic frame (Malina and Rarick, 1973). Similarly, early maturing boys and girls are on the average stronger than later maturers. There is some evidence that isometric strength training produces relatively greater strength in prepubescent than in the post-pubescent years (Rarick and Larsen, 1959). That boys are generally stronger than girls per unit of weight is well known. This is not only because boys are the more active group, but because they have relatively more muscle tissue per unit of weight than girls and can utilize the muscle tissue they have more effectively than girls in tests of strength (Rarick and Thompson, 1956).

Working Capacity. Cross-sectional studies show that the working capacity of children as assessed by bicycle ergometer tests (submaximal tests and tests of maximum oxygen uptake) increases through the years of childhood (Adams, et al. 1961; Bengtsson, 1956; Rode and Shephard, 1973). At a given heart rate the working capacity in children increases linearly from 5 - 14 years (Bengtsson, 1956). The boy of 5 - 6 years has a working capacity of 20% of the adult male, the boy of 7 - 9 years 28% of the adult, and the boy of 10 - 12 years 44 per cent of the adult male (Bengtsson, 1956). Studies of sex differences in working capacity of boys and girls have generally shown that the working capacity per unit of surface area is greater in boys than in girls, the difference becoming greater with advancing age.(Adams, 1961).

It is well established that endurance training will substantially increase working capacity, and it is equally well known that once training stops the physical working capacity moves back to the pre-training level. Unfortunately, we have very little longitudinal data on children who have followed rigorous exercise regimens over a period of several years. Adams (1961a, 1961b) reported that Swedish school children who engaged in a rigorous program of physical training had substantially higher physical working capacities than those who were poorly trained, there being no difference between urban and rural children.

Adams' research has been supported by Ekblom (1969) who reported that 11 year old boys exposed to two 45-50 minute training sessions per week (interval training) for a period of six months increased their aerobic capacity 15% more than a reference group. A subsequent 26 months of vigorous sports club activity by five of the subjects resulted in approximately a 50% greater improvement than was noted in non-trained controls. However, it should be noted that the increase in oxygen uptake per unit of weight in the exercise and the control subjects was approximately the same. The exercise group showed substantially the greater increase in muscle mass, thus accounting for the greater oxygen uptake. Ekblom points out that if the desire is to develop an "athletic physique", hard physical training must be started early in life, for it appears that the effectiveness of the growth hormone at this stage of life is accentuated during periods of vigorous physical training.

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While only limited study has been done on endurance training with young girls, the physiological effects are dramatic. For example, 8 - 13 year old girls involved in six and twelve weeks of cross-country running increased their mean maximum oxygen uptake 18% over resting levels at the end of the 6th week, and 26 per cent above resting levels by the end of the 12th week. (Brown et al, 1972) The training sessions were held four or five days each week and lasted from one to two hours. By the middle and late season the runners were able to cover four to seven miles. According to the investigators the functional adaptability of pre-adolescent girls to endurance training is as great or greater than adolescent girls or adults.

<u>Social-Psychological Development</u>. Competence in sports is held by some to be a potent factor in the social-psychological development of children. General observation of children would tend to support this belief. That skill in physical activities is positively associated with measures of social acceptance in children has in fact been shown by numerous studies (Hardy, 1937; Rarick and McKee, 1949; Jones, 1949). On the other hand, it may well be that other characteristics, themselves independent of the child's motoric skills, may have been operating to influence the child's social behavior. To date no well controlled studies have been done which have assessed the changes in social behavior as a function of improvement in motor proficiency.

<u>Concluding Comment</u>. This paper has brought together in a fragmentary way some of the research pertaining to the effects of physical activity on children. It is clear that the gaps in knowledge, which are many, reflect the short term nature of motoric research. But, longitudinal studies are difficult to manage.

The positive effects of physical activity on the growth and development of children are becoming evident. What we do not know and may never know with precision is the nature, intensity, and duration of physical activity which is best for a given child.

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