The Effect of Physical Activity on Physical Growth and Development

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Since the effect of physical activity on the functional aspects of growth and development of children is dealt with elsewhere in this volume, this review is limited to the following structural areas: body dimensions and proportions, body composition, and maturation. One of the difficulties in assessing the effect of physical activity on growth and development lies in the definition of physical activity itself. For the purpose of this review, observations are made about (a) habitual levels of physical activity (including regular physical education), (b) additional or special physical education programs, and (c) intensive training programs in competitive sports.

In spite of the many studies that have been conducted to investigate the acute effects of exercise on structural and functional aspects of the human body, relatively little is known about the long-term influence of habitual physical activity levels and exercise programs on the growth and development of children and adolescents. As Cumming (1976) expressed it,

A minimum of physical activity is likely necessary for optimal growth or development of children, but this minimum will likely never be known with certainty, just as the minimal activity patterns for the health of adults are likely to remain unknown. We cannot even define optimal growth and development, either in generalities or in specifics such as height, or heart volume, or maximum oxygen uptake. (p. 67)

A phenomenon that certainly appears related to optimal growth or development of children is the secular trend of accelerated maturation and increase in body size which began in many industrialized countries in the middle of the 19th century (see Malina, 1979, 1983a; Roche, 1979). In general, the trend is thought to be due to elimination of growth-inhibiting factors rather than to addition of growth-stimulating ones. Although some researchers still propose unicausal explanations for the trend (cf. Adams, 1981; Chiarelli, 1977), most investigators point to the interaction of a multitude of factors. The most prominently mentioned causes are better nutrition, improved health care and health status, improved socioeconomic conditions, increased urbanization, and genetic factors. In some western countries, the trend has now either slowed down or stopped altogether (Malina, 1983a).

Interestingly, exercise or physical activity is seldom mentioned as a contributor to this secular trend. Malina (1979) includes exercise among the factors that have created better living conditions but acknowledges at the same time that levels of habitual phys-
ical activity may have decreased as a result of industrialization. It would be difficult, therefore, to urge that the trend was caused in part by higher levels of physical activity. Nevertheless, the changes in growth and development exhibited by the secular trend can serve as a yardstick in assessing the effect of various levels of exercise on the growth of children and adolescents.

**BODY DIMENSIONS AND PROPORTIONS**

It is not difficult to find diametrically opposed statements concerning the effect of exercise on body dimensions in the general physical education literature. This is especially true for physical activity involving intensive training for sport competition. Edington and Edgerton (1976), for example, write that “potentially beneficial effects of exercise on general body growth have been noted in healthy young boys and girls (late teens) who had engaged in strenuous physical exercise during their childhood: they grow taller and heavier with larger chest girths and knee joint widths’’ (p. 220). Here, physical activity is clearly presented as growth-promoting, but the reader is left without references to primary sources.

On the other side of the ledger is the statement of Paulac (1982):

>We have noticed over a long time the influence of intensive exercises on the joining cartilages, which brings on premature ossification, and of the hypertrophy muscles [sic], a real height reduction which is not expressed by the ‘‘genotype,’” that is to say the “‘initial plan’” of the genetic programme. (p. 80).

Once again, this assertion that strenuous exercise serves as a growth-inhibiting factor is not corroborated by factual evidence.

The secular trend of accelerated growth from 1850 to 1960 led to an increase in stature of approximately 1.3 cm per decade at age 9, 1.9 cm at age 13, and .6 cm at adulthood (Roche, 1979). As discussed earlier, researchers did not link these increases in height to physical activity levels or improved exercise habits. At the same time, strenuous exercise is described in physical education literature as both growth-promoting and growth-inhibiting. What is the evidence with respect to stature and exercise?

**Stature**

Some of the generalizations about physical activity as a growth-promoting or growth-inhibiting factor may have been derived from older studies that have been reported in earlier reviews (Malina, 1969; Rarick, 1974). Adams (1938), for example, found that black women between the ages of 17 and 21 who had engaged in strenuous labor during childhood were taller, heavier, and had larger girths and bone widths than a control group of women who did not engage in heavy labor during youth. The problem with the Adams study and other ex post facto observations is that there is no guarantee the two groups of women were equivalent before the period of heavy work started. In fact, Adams indicated that the two groups were sampled from two entirely different
socioeconomic milieux. The differences, therefore, may have been caused by other variables than the work load.

Similar reservations must be made with respect to a study by Kato and Ishiko (1966), who found 116 cases of obstructed epiphyseal growth in the lower extremities of Japanese children who engaged in hard labor. The researchers observed premature closure of the femoral, tibial, and fibular epiphyses and related this to compressive stress from heavy loads carried on the shoulders. As Malina (1969) indicated, however, the children came from a very poor environment with substandard nutrition. Even so, more than 97% of the children examined did not show symptoms of marked premature closure.

The overwhelming evidence from studies with equivalent control groups is that extra classes of physical education (Kemper et al., 1974; Shephard, Lavelle, Jequier, Rajic, & LaBarre, 1980), special physical education programs (Coonan et al., 1982), or more strenuous physical training (Parizkova, 1968; Wyznikiewicz-Kop & Kobuszewska, 1980) do not affect growth in stature. In the Kemper study, students received two extra classes of physical education a week over a 1-year period; Shephard reported on the Trois-Rivières regional experiment in which children received four extra physical education classes per week over an 8-year period. Coonan reviewed a number of Australian research projects in which the effects of fitness training and skills treatment were studied. Parizkova followed groups with varying levels of physical training and activity over a 4-year span, and Wyznikiewicz-Kop contrasted young athletes with nonathletes over a period of 3 years. Although significant findings were observed in functional variables in some of these studies with preadolescent and adolescent children, differences in stature were found to be insignificant.

**Bone Width and Density**

As Cumming (1976) noted, a lot more is known about the effect of inactivity upon bone growth and skeletal changes than about the effect of intense physical training. Although there are many examples of bone hypertrophy as a result of prolonged physical stress (e.g., the width of the dominant wrist and elbow in tennis players), it is still hard to tell whether active children have any skeletal advantages over relatively inactive children in later years (p. 68). Scientists in the Soviet Union and Yugoslavia have been particularly interested in sport-specific osteogenesis. In Leningrad, studies have been conducted both at the Pavlov First Medical Institute and the Lesgaft Institute of Physical Culture.

Rjazanova (1980) studied the skeleton of the hand and wrist roentgenographically and osteometrically in two groups of swimmers, ages 8 to 10 and 17 to 19 years. Both age groups showed accelerated synostosis compared to control groups of nonathletes. In the younger group the difference was attributed largely to a selection factor, as these children had not engaged in strenuous workouts for any length of time. Compared to basketball players, however, the older swimmers had significantly longer metacarpal bones of the left hand, but not of the right. The same was noted for the thickness of these bones. Whereas basketball players showed advanced development of the dominant hand, the older swimmers had uniform lengthening and thickening of the metacarpal bones of both hands.
Korneva (1979) compared two groups of volleyball players (13 to 14 years and 15 to 16 years old) to children who did not participate in competitive sports. For both age groups, the second metacarpal bone of the volleyball players was significantly longer than that of the controls. In the older group, the thickness of the compact bone layer of the metacarpals was larger in the athletes than in the controls. This greater thickness was accompanied by a narrowing of the osseomedullary canal. Volleyball players showed a delayed synostosis compared to controls. Kornev (1980) found a delayed ossification of the distal epiphyses of radius and ulna and the bones of the hand and wrist of male adolescent boxers and soccer players compared to basketball players of the same chronological age (15-17 years). Mineralization of the metacarpals, however, was most pronounced in boxers and least developed in soccer players. Prives and Aleksina (1978) stated that different kinds of sport have different effects on the ossification of the tubular bones. The process of synostosis, according to these researchers, depends not only on genetic factors but also on environmental ones including physical activity.

Several Yugoslavian studies have dealt with the influence of strenuous physical activity on the development of the pelvis. Kliment, Schmidt, and Zajac (1971), for example, concluded that competitive skiing does not affect the inner dimensions of the pelvis (parturient canal) adversely. In women who started ski training before the age of 15, however, the authors found a conjugata externa of less than 18 cm in 75% of the cases. In a control group of competitive swimmers, such low values were not found. In a later investigation, Kovacikova (1978) compared the external pelvic dimensions of three groups of women: competitive athletes, physically active nonathletes, and women who did not exercise. A statistically significant narrowing of the pelvis in all measured dimensions was observed in the competitive athletes when compared with the other two groups. The author attributed the difference to a combination of constitutional (selection) and environmental (physical exercise and sport) factors. The Yugoslavian authors expressed caution with respect to excessive physical stress for women during puberty.

**Proportionality**

Secular increase in height and other dimensions have been approximately proportion- al, so overall body shape and proportions have changed little (Charzewski & Bielicki, 1978; Malina, 1983a). Some studies (Eiben, 1978; Eveleth & Tanner, 1976) have reported a tendency toward smaller trunks and increasing linearity in the secular trend. Little evidence is available about the effect of exercise on body proportions. Warren (1980) observed that a group of adolescent ballet dancers who were studied over a period of 4 years had a significantly increased arm span and a decreased upper to lower body ratio compared to other female members of their families. She related these differences to a delayed menarche as a result of energy drain, although she did not rule out the possibility of selection. Parízková (1968) found that boys classified in a high activity group had significantly lower ratios of pelvic width to height and shoulder width than boys in lower activity groups after the 4th year of observation. No significant differences were found during the first 3 years of the study. Since classification into activity groups occurred ex post facto, such differences should be interpreted with reser-
viation. In general, there is little to suggest that even strenuous physical training affects body proportionality.

**BODY COMPOSITION**

The secular trend in body weight from 1850 to 1960 saw an increase per decade of .8 kg at 10 years of age, 1.8 kg at 15 years, and .9 kg at 20 years of age (Roche, 1979). Over approximately the same time span, Himes (1979) showed that the ratio of mean weight to stature for 9-year-old boys generally increased. Such changes may indicate merely a pattern of acceleration rather than a change in the relationship between body weight and stature, since the weight-height ratio for boys increases with age during normal development. Himes noted, however, that subcutaneous fat tissue has increased over the past decades. Evidence of this trend is supplied by Tanner and Whitehouse (1962, 1975) and more recently by the National Children and Youth Fitness Study (Pate, Ross, Dotson, & Gilbert, 1985). In these studies, the increase in subcutaneous fat appears to be more significant in the upper percentiles. Himes speculated that if fat tissue has increased at a faster rate than total body weight, then younger generations should have greater absolute strength (larger bulk) but less strength relative to body weight (smaller proportion of lean body mass). The secular trend in body composition is therefore not a desirable one.

**Habitual Physical Activity**

The increase in childhood obesity has often been linked to increased food intake coupled with a lack of physical activity. Automation in industrialized society and the appeal of television to children as well as adults have been mentioned as causes for a presumed decline in physical activity patterns. However, it is difficult to find objective evidence about the activity patterns of children and adults at various points in history. Kemper et al. (1983) and Verschuur et al. (1984) did establish that habitual physical activities of teenagers decline with age. In a carefully designed longitudinal study, they defined activity patterns as the "total activity time spent per week on physical activities with an energy expenditure of 4 METs [multiples of metabolic resting equivalents] or more" (1983, p. 211). Over a period of 5 years (ages 12 to 17), the activity time for girls dropped from 9.5 to 8 hours per week whereas the boys showed a decline from 10 to 7.5 hours.

When Kemper analyzed the activity patterns in terms of intensity, he found that girls actually increased their number of hours of light activities (4-7 METs) but spent little or no time in heavy activities (over 10 METs). Over the period of study, percentage body fat for girls increased from 23% at 12 years to 28% at age 17. Since girls normally increase their body fat percentage during adolescence, the increase could not be causally linked to the decline in heavy activity patterns. Boys during the same period maintained the same level of heavy activities. Their mean percentage body fat remained stable at 16% from ages 12 to 17.

The recent National Children and Youth Fitness Study included an extensive section devoted to activity patterns. Ross, Dotson, and Gilbert (1985) concluded on the
basis of this study that approximately half of the American children in grades 5 through 12 do not meet the minimum weekly requirement of vigorous physical activity necessary for an effectively functioning cardiorespiratory system. This minimum weekly requirement is based on a position paper by the American College of Sports Medicine (1978) and modified somewhat in a report by the U.S. Department of Health and Human Services (1980). It recommends "exercise which involves large muscle groups in dynamic movement for periods of 20 minutes or longer, three or more times a week, and which is performed at an intensity requiring 60 percent or greater of an individual’s cardiorespiratory capacity" (p. 79). One must remember, however, that these guidelines were originally drawn up for healthy adults and that they address mainly cardiorespiratory fitness.

Additional Physical Education

There is ample evidence that carefully designed activity programs can be effective in reducing percentage body fat in adults as well as children. Since 1977 a number of research projects investigating the effects of daily physical education programs have been conducted in various parts of Australia. Coonan et al. (1982) reviewed the results of the School Health, Academic Performance and Exercise Project (SHAPE) which involved more than 500 10-year-old boys and girls. Children in the control group received the regular physical education program of three half-hours per week of motor skills work; one experimental group participated in a fitness training program of 1 1/4 hours each day; and a third group took part in a skills treatment program of similar duration to the fitness training. After the 14-week experiment, children in the fitness training program showed a significant reduction in subcutaneous fat as measured by the sum of four skinfolds. Children in the skills program did not differ significantly from the controls on the skinfold variable. A follow-up study of SHAPE confirmed the effectiveness of the project but also indicated the need for close adherence to the exercise objectives.

Kemper et al. (1974) did not find significant differences in body composition between 12- and 13-year-old boys who received daily physical education for 1 hour and controls who had 3 hours of physical education per week. The extra 2 hours were an extension of the normal physical education program which aimed mainly at improving motor skills. The results of this Dutch study appear to corroborate the Australian findings that an increase in time alone may not produce significant changes in body composition. An additional Australian study, the so-called Body Owner’s Project, focused on the use of health courses to improve physical health status. Children who were taught to monitor their activity behaviors and record them did gain health benefits, including reduced skinfold measures, over and above those arising from unmonitored daily physical education (Coonan et al., 1982, p. 241). Parizkova (1968, 1970) found that the differences among groups of boys with different physical activity patterns were most pronounced in body composition. After 4 years of longitudinal observation, boys in the highly active group had significantly less fat and more lean body mass than the boys in the low activity group. These groups of 15-year-olds had not shown any differences at the beginning of the study when they were 11 years old. She also reported on several successful summer camp programs that combined diet and exercise in the treatment of obese children (Parizkova, 1973).
Intensive Training Programs

As Cumming (1976) noted, physical exercise is important in childhood for weight control. Children who participate in competitive sports seldom show problems of obesity. Parizkova (1973) demonstrated significant differences in the body composition of young male and female athletes in various sports when compared with controls. Invariably, the young athletes had a lower percentage body fat and a larger percentage of lean body mass. Motajova (1974) showed similar differences over a 4-year longitudinal study between young athletes and children who only participated in school physical education. Since it is impossible to assign children randomly to control groups and athletic competition, comparisons between athletes and controls should be interpreted with caution. It is most likely the children with favorable physiques and body composition who will be drawn to competitive sports. Nevertheless, there is little question that strenuous training programs in combination with an appropriate diet will reduce the percentage of body fat. In such situations, the problems that arise are more often related to excessive leanness than to obesity.

MATURATION

One of the more remarkable features of the secular trend has been a pattern of accelerated growth. This aspect of the trend is best illustrated by the decrease in the age at menarche (the time of first menstruation). In many countries, age at menarche decreased at a rate of 4 months per decade from the middle of the 19th century until recently. There is no evidence that the trend of earlier maturation can be linked to changes in habitual physical activity patterns. Equally, there is no evidence that additional programs of moderate intensity influence the rate of growth of the skeleton and the reproductive system. In the area of competitive sports for children, however, the maturational question is important because in some sports delayed maturation has been observed, especially in girls.

Strenuous Training

As mentioned earlier in the section on body dimensions, there are widely divergent opinions about the effect of strenuous exercise on growth. Such opinions are reflected in the research literature. Evidence for accelerated growth in height as a result of a training program comes from a widely quoted study by Ekblom (1969) in which five subjects in the training group showed a greater height increase over a 32-month training period than a group of four control subjects. The design of this study and its small sample size hardly allow for any generalization. No skeletal age assessments were made for these early adolescent boys. If some of the experimental subjects were late matures, that fact alone could explain the catch-up growth during the latter part of the study. Equally unconvincing is a report by Delmas (1981), who studied 11 girl and 8 boy gymnasts between the ages of 8 and 16 years over a period of 18 months. The author found a "break" in the growth curve of height in two-thirds of these children. This observation is confounded further by the fact that the young athletes were on an ex-
tremely restricted diet. Needless to say, there is a great need for controlled studies in this area.

Delayed Menarche

On the average, menarche occurs later in athletes than in the general population. This phenomenon has been observed for a number of sports, but cross-culturally it has been especially consistent in such sports as figure skating, gymnastics, long-distance running, and ballet. Swimmers appear to be an exception to this trend according to most of the observations in this area. An excellent review of menarche in athletes is provided by Malina (1983b), who also addressed the question of causation. Since it is impossible to design studies in which children are randomly assigned to competitive athletics, it is very difficult to isolate intense physical training as the primary cause for the phenomena of delayed menarche and amenorrhea. One of the strongest rival hypotheses is that of systematic selection. In a number of sports, late-maturing girls, for structural as well as functional reasons, have an advantage over early maturers. This is especially so in ballet, gymnastics, and certain events in track and field. In such sports, the process of selection would increasingly favor late-maturing girls at higher levels of competition.

The mechanisms by which strenuous training could influence the timing of menarche are not clearly understood. Frisch et al. (1974, 1976) postulated that a critical percentage of body fat (approximately 17%) must be reached before the onset of menstruation, and that 22% body fat is desirable for maintaining regular ovulatory cycles. Primary and secondary amenorrhea would thus be caused if, due to strenuous training, the percentage body fat dropped below these levels. This so-called critical weight theory, however, has not found universal acceptance (see Malina, Spirduso, Tate, & Baylor, 1978; Trussell, 1980). In a longitudinal study of early adolescent ballet dancers, Warren (1980) concluded that, in addition to low body weight and percentage body fat, an energy drain may have had a significantly modulatory effect on the hypothalamic pituitary set point at puberty, resulting in a prolonged prepubertal state and induced amenorrhea. Menarche in this group was significantly delayed in comparison to controls, occurring at a mean of 15.4 years. Warren noted that pubertal development accelerated for these girls during periods of planned or forced rest.

Frisch et al. (1981) found that the age at menarche in groups of 21 college swimmers and 17 runners was positively related to the number of years these women had trained premenarcheally. Each year of training before menarche delayed the onset of menstruation by 5 months. The mean age at menarche for the 20 athletes who started training postmenarcheally was 12.8, whereas the mean age for the 18 girls who started training before menarche was 15.1 years (p. 1560). Frisch et al. also noted significant differences between the pre- and postmenarcheal groups in cycle irregularity and amenorrhea. A similar observation was made by Levenets (1979) for 205 Russian adolescent athletes, 24.8% of whom had oopsomenorrhea or secondary amenorrhea. Malina (1982) criticized the findings of Frisch et al. on the basis of the small and seemingly unusual sample of athletes (12 swimmers and 6 runners) who started training before menarche. The findings were unusual in that the age at menarche of swimmers in the majority of studies approximates the mean of the general population. Malina also pointed out that the correlation between age at menarche and years of premenarcheal training does not imply a cause and effect relationship.
The relationship between years of premenarcheal training and age at menarche appears to be corroborated in an overview by Märker (1981) in which menarcheal age is reported by sport and related to the beginning of training. The author observed that delayed menarche occurs more frequently in gymnastics, figure skating, and diving than in other sports. Since girls in these sports begin training at an earlier age than in other sports, there appears to be at least an inferred relationship between the age at which strenuous training begins and the age at menarche. Märker noted, however, that athletes with late menarche experienced no ill effects with respect to their reproductive functions, based on data gathered on childbirth. In spite of the differences in age at menarche among athletes in different sports, the age at parturition showed no predictable pattern. Gymnasts, who had the highest mean age at menarche, were among the youngest in age at parturition. The author concluded that fertility was not impaired by the intense training started during early childhood.

Figure 1—Number of years of training before menarche of female athletes from different sports (Märker, 1981).

CONCLUSIONS

If one thing became clear during the preparation of this brief overview, it was the difficulty of isolating the factor of physical activity and its effect on the growth and development of children and adolescents. Factors such as exercise should never be considered in isolation, as there is always a complex interaction of both genetic and environmental variables. This makes the design of controlled studies very problematic. Most of the studies reviewed relied on post hoc observations that allowed for a number of alternate explanations. There is no conclusive evidence that physical activity, even of high intensity and duration, markedly affects growth in stature and body proportions. Neither is there conclusive evidence that moderate or strenuous exercise during childhood accelerates the growth process. Research on female athletes presents some presumptive evidence that strenuous physical training before menarche delays the onset of puberty and prolongs the prepubertal stage. The mechanism(s) underlying this phenomenon are not clearly understood. Although fertility and reproductive functions do not appear to be endangered by strenuous physical activity before puberty, research
findings of smaller pelvic dimensions and increased incidence of irregularity and amenor-
hea need to be followed up in better-controlled investigations.

Habitual levels of physical activity of children and adolescents decline with age. Children who remain active in additional programs of physical education or competitive sport show the benefits of this training in a lower percentage of body fat and a larger percentage of lean body weight compared to more inactive children. To maintain or attain desirable standards of body composition, programs of physical education have to be carefully designed both with respect to duration and intensity. Australian and Dutch studies showed that merely increasing the length of time of traditional physical education programs will not of itself lead to desirable changes in terms of body composition. If time is limited, the emphasis of physical education programs should be on teaching activities that will be carried on after school. Experiments with daily physical education periods supported by physical health classes have shown that developmental and fitness objectives, including the control of obesity, can be reached if these programs are properly monitored and supported.

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