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Trainability *of* Children

Use research on growth patterns and neural, muscular, skeletal and hormonal development as guides for tailoring kids' exercise program design.

While there is a general trend in developed countries for children to be less active and more obese (Tremblay & Willms 2000; Pate & Trost 1998), there is also a trend to physically train children who participate in sports at younger and younger ages (American Academy of Pediatrics 2000). From a general training and sport development perspective, however, it is essential to account for differences in growth and maturation when designing a training curriculum. >>

Too often, children's programs are modeled after those designed for adults or even those meant for professional athletes. While fuzzy logic would suggest that "what is good for the goose is good for the gander," to date there is no evidence that early exposure to rigid training programs designed to develop the primary components of fitness lead to increased levels of performance later in life.

Recent results describing the trainability of children are often mixed and controversial (Faigenbaum & Bradley 1998; National Strength and Conditioning Association [NSCA] 1996; Bar-Or 1989; Sailors & Berg 1987; Roemmich & Rogol 1995; Baquet, Van Praagh, & Berthoin 2003). Studies examining youth trainability have been fraught with methodological problems, often using nonrepresentative samples of children, small subject pools, and poor controls to account for the normal growth and maturation process. This article will review the literature pertaining to the trainability of children and examine the ability to create favorable adaptations in prepubertal, pubertal and postpubertal children.

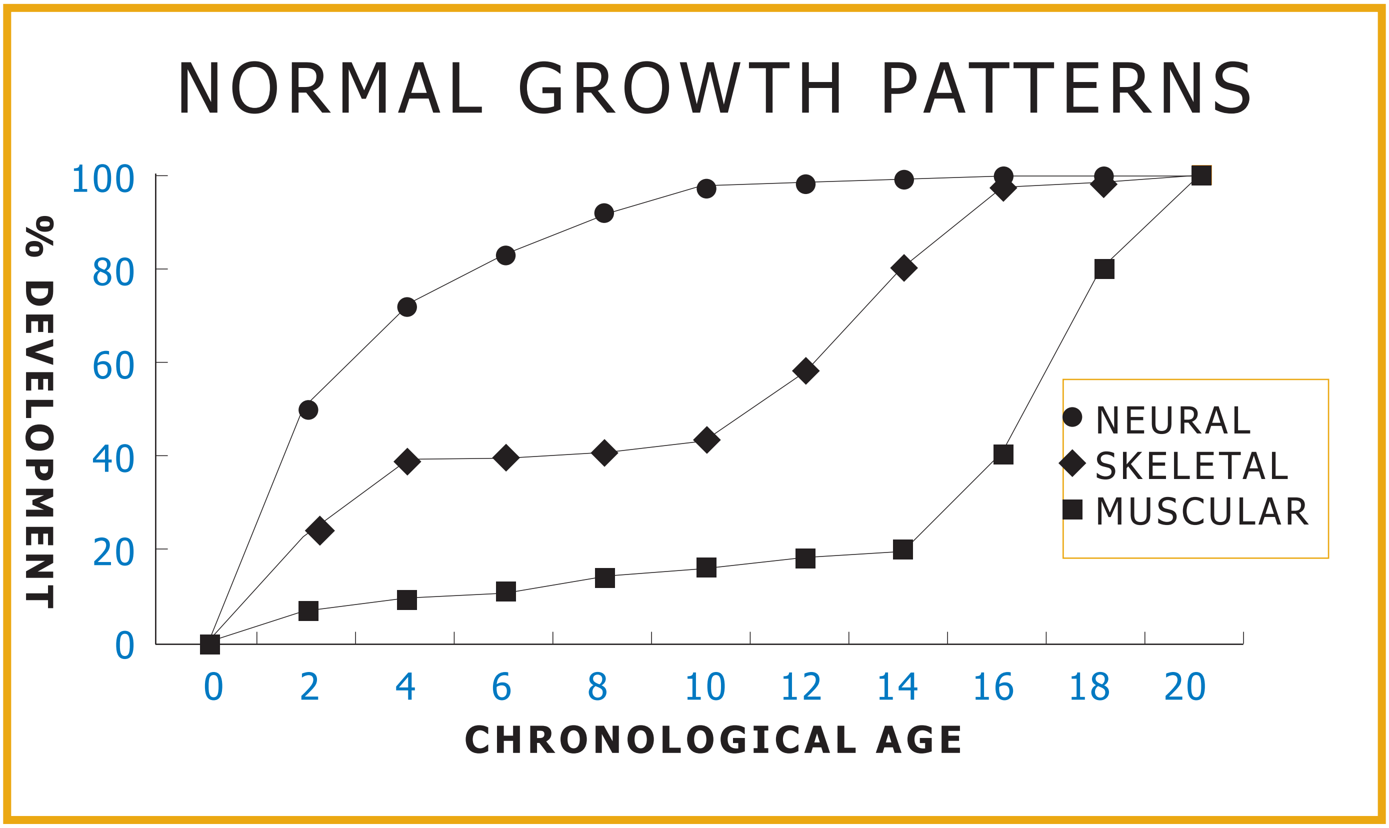
Child Growth and Development

Human growth can be described at a basic level as measurable changes in body size, shape and composition; at a functional level, it can be described as the development of the nervous, skeletal and muscular systems (see "Normal Growth Patterns," below). While there is great variation in the timing (age) and tempo (rate) of growth, the sequence or pattern of growth itself is common to all children (Malina & Bouchard 1991; Roemmich & Rogol 1995). For example, among a group of 12-year-olds there may be one who is 4 feet 3 inches tall and another who measures 5 feet 9 inches, but in each child the feet will grow before the trunk, and the trunk will lengthen before breadth is added.

During adolescence, children of similar chronological age may vary significantly in their progress toward the mature adult form and may therefore exhibit great size and strength differences. As chronological age is only a general indicator of developmental status, age-restricted categories can often be misleading (Anderson & Ward 2002). For the purpose of this discussion, the terms *prepubertal* and *postpubertal* will be used, with peak height velocity marking the transition between the two.

Prepubertal children are those who have not yet gone through their adolescent growth spurt, or their period of most rapid growth (peak height velocity). Prepubertal children are often younger than 12 years of age if female and younger than 14 if male.

The **pubertal** phase of peak height velocity lasts 12–18 months and brings with it several training considerations. It is impossible to provide a generic program for this period owing to differences in the rate and timing of maximal growth. General considerations include reduced distal loading of the limbs and reduced high-intensity work to avoid overtraining or inflammation



of the bone-tendon connections. During this period the levers increase in length, whereas the muscles do not respond until later, leaving these children at a lever disadvantage. Even basic locomotor skills may appear awkward during this phase.

Postpubertal children are those who have experienced their adolescent growth spurt, or peak height velocity, but have not yet reached full skeletal maturity. After peak height velocity, postpubertal children experience an accelerated increase in mass, with rapid gains in muscular development, along with further hormonal maturation. While the chronological age may vary dramatically during this phase, postpubertal females will be 13–17 years of age, and males 15–18.

increases, whereas relative oxygen consumption (milliliters of oxygen per kilogram of body weight per minute) remains fairly constant. Naturally, children's performance times for endurance exercise decrease (e.g., a 14- to 15-year-old boy will run 1,500 meters almost twice as fast as a 5- to 6-year-old boy). However, even a sedentary child will have what appears to be a cardiovascular training effect as a result of normal growth. A child who performs no physical activity will have a gradual decrease in resting heart rate, an increase in cardiac output and an increase in absolute oxygen uptake. This is a typical phenomenon: Relative max VO_2 remains stable during growing years, while endurance performance improves. Increases in running ability may well be related to improved running economy and efficiency, increased muscle mass and greater stride length; or they may be related to relative body composition changes during growth (Bar-Or 1989).

TABLE 1. RECOMMENDATIONS FOR TRAINING AEROBIC CAPACITY IN CHILDREN

	PREPUBERTAL	POSTPUBERTAL
Frequency	3–5 days per week	4–5 days per week
Intensity	> 170 bpm	> 140 bpm
	> 85% maximal HR	> 70% maximal HR
Time	15+ minutes	20+ minutes
Type	continuous or interval	continuous
Note	Adherence to continuous programs may be low.	Interval training may be added for additional benefit.

Key: bpm = beats per minute; HR = heart rate

Primary Fitness Characteristics

Primary fitness characteristics include aerobic capacity, muscular strength and endurance, and flexibility.

Aerobic Capacity

Aerobic capacity represents a person's ability to take up and use oxygen for the purpose of energy production. Aerobic capacity depends on the person's ability to move air into the lungs (pulmonary ventilation); the diffusion of oxygen into the bloodstream; the blood's oxygen-carrying capacity (related to hemoglobin); the heart's ability to pump blood (represented by cardiac output); distribution of blood within the tissues (related to capillary density); and the tissue's ability to extract the oxygen and use it for the purpose of energy production (related to muscle myoglobin and mitochondrial density). Training to improve aerobic capacity must target one or more of these critical elements, which are also closely related to normal growth and development.

During normal growth, the absolute amount of oxygen (liters per minute) one can take up and use will increase as muscle mass

Trainability

A person's aerobic capacity is the product of cardiac output (how much blood the heart can circulate to the tissues) and the arteriovenous oxygen difference (the tissue's ability to extract the oxygen). Improvements in either oxygen delivery and/or extraction improve one's aerobic capacity.

With an increase in organ size during normal growth, the heart is capable of pumping more blood. This allows an older child to rely less on increased heart rate to pump blood and more on increased stroke volume, or the amount of blood pumped by the heart per beat. Because of increases in stroke volume, resting and submaximal exercising heart rates go down throughout childhood. Increases in stroke volume with age have major implications for improving aerobic capacity because of the positive impact on cardiac output and, thus, VO_2max.

The oxygen extraction capability (A-VO_2 difference) of untrained children is relatively high in comparison to that of untrained adults. Children extract and use more oxygen per liter of blood pumped than their adult counterparts, with children having relatively high aerobic capacities compared to adults. Given how high the oxygen extraction rate is in youngsters, many researchers believe that this is not a trainable component in children and that children can increase aerobic capacity only by increasing cardiac output. While this has not been proven in the literature, studies continually report a blunted training response in children, demonstrating a training effect only half as great as expected in young adults following similar training programs.

Early studies suggested that the aerobic capacity of prepubertal children was difficult to improve, while Katch (1983) suggested there might be a critical period (such as puberty) before which training adaptations were limited. More recently, however, several studies have documented increases in aerobic capacity with an adequate training stimulus (Pate & Trost 1998; Baquet, Van Praagh & Berthoin 2003). More specifically, it appears that exercise intensities for prepubertal children must be higher than those for young adults—requiring heart rates of 170–180 beats per minute, or approximately 80%–85% of maximal heart rate (75% of heart rate reserve)—for training adaptations to be realized (Pate & Trost 1998; Baquet Van Praagh & Berthoin 2003).

While training adaptations can occur in the prepubertal population, they appear to be blunted (Tolfrey, Campbell & Batterham 1998). Baquet and colleagues (2003) reviewed training studies and found an average increase in VO_2max of 10% (7% more than would be expected as a consequence of normal growth). However, similar training programs in young adults would typically see improvements of 10%–20% in aerobic capacity over the same time frame. Thus, while it appears that aerobic capacity can be trained in young children, the exercise intensities must be higher than those typically prescribed to postpubertal populations, and the training response will be only about 50% of that expected in young adults.

Program Design

The trainability of the systems supporting increased aerobic capacity is well documented in postpubertal children; however, many factors involved in training prepubertal children remain controversial. While prepubertal children appear to be physiologically adaptive to endurance exercise training, most studies suggest that the training must be at a high level of intensity. Table 1 provides some general recommendations.

Keep several factors in mind when designing an aerobic training program for children. First, a program must be fun! Second, it is important to increase frequency rather than duration, as children do not naturally perform prolonged, steady-state types of exercise. Third, to prevent boredom, be sure to incorporate cross-training and multiple activities such as interactive or interdependent games, relays and exploratory learning activities.

Postpubertal children will respond well to the traditional training guidelines provided by the American College of Sports Medicine (ACSM) and others. During the period of rapid growth, watch for symptoms of overtraining. Muscles are put at a lever disadvantage during this period and are typically tight, putting stress on the tendons and bones of the long levers. To avoid overuse injuries during this period, you may need to reduce training volume.

Muscular Strength

Muscular strength is the maximum amount of force that a muscle or muscle group can generate against an external load. It is an integrated expression of conditions in the nervous, muscular and endocrine systems, the age and maturation level of the child, and the environmental conditions. Muscular strength is closely related to muscle size or cross-sectional area—a larger muscle can generate more force. While muscles normally grow during childhood, there is a naturally occurring increase in strength, with a more rapid increase in strength approximately 12–18 months after a child's adolescent growth spurt. This increase is linked to increased levels of circulating androgens—particularly, testosterone.

Resistance training can be defined as the use of progressive resistance exercise to increase one's ability to exert or resist force, encompassing a wide range of overload to the muscles through the use of a variety of training modalities (Faigenbaum & Bradley 1998). Muscle adaptations to resistance training may include both neural (increased motor unit recruitment) and biochemical (muscle hypertrophy) components (Blimkie 1992).

While resistance training in children and youth was condemned by early research as lacking benefit and posing undue risk, this is now an antiquated view. ACSM, the American Academy of Pediatrics and NSCA all support the practice of resistance training in prepubertal and adolescent children. And while it was once thought that young children could not benefit from strength training because they had insufficient levels of circulating androgens, recent research clearly demonstrates that young athletes can achieve marked increases in specific and nonspecific strength through a properly designed and supervised strength training program (NSCA 1996).

Trainability

The nervous system is highly trainable at a young age, and strength gains can be seen with no increase in muscle size. For this reason, prepubertal children who are exposed to a properly designed resistance training program can increase strength through the development of proper neural-recruitment patterns and increased nervous-system activation (Blimkie 1992). For example, in the initial stages of a training program, large increases in strength are often realized without muscle hypertrophy or increased muscle size. This rapid increase is due to neural adaptations.

In adults, the rapid neural adaptations to resistance training are followed by slower biochemical adaptations, during which the muscle grows in size. This hypertrophic period is, however, linked to circulating androgens, so among youngsters it is limited to postpubertal children and is more evident in males than females.

Program Design

As the nervous system is almost completely mature by the age of 7 years, muscular strength is a trainable component at an early age. The strength increases will come from education in correct technique, as gains are linked to better neural coordination and recruitment patterns. For pre- and postpubertal children, learning perfect form and proper technique early in their training is essential—and more important than lifting heavy weight.

From the literature, it appears that 1 set of 13–15 repetitions that end at the point of fatigue is the best stimulus for adaptation for prepubertal exercisers (Faigenbaum & Westcott 2000). This is most important at the start of a strength training program, as children may perform a single set to fatigue to achieve gains in strength, reducing the time required in the weight room. However, as the lower body can do a greater number of repetitions at any given percentage of 1RM, increasing the number of repetitions performed for lower-body exercises is also prudent (Sale 1989).

The weight selected for new exercises should be an amount they can lift a minimum of 20 times with proper form and breathing. Once optimal technique is demonstrated, select a load that allows 13–15 repetitions per set, under control. Since kids tend to do things quickly and move ballistically, it is advisable to coach a controlled tempo, taking 2–3 seconds on both the concentric and the eccentric lift phases to maximize strength development and minimize risk of injury (Faigenbaum & Westcott 2000). Once children are proficient at a basic program, increase the training frequency from 2 to 3 times per week, increasing the number of sets from 1 to 2 or 3, or increasing the number of exercises performed. Choose one of the above; do not increase all three variables at once. For children involved in other activities, increasing the number of sets per exercise will improve results without adding training day to their schedule. See Table 2 for guidelines on frequency, intensity and type of strength training.

Flexibility

Flexibility is the capacity of a joint, or series of joints, to move through a full range of motion (ROM) without undue strain. Full ROM is essential for proper movement and helps determine a person's ability to move freely and efficiently. Flexibility is limited by the length of muscles, ligaments and tendons, the joint structure and the joint capsule, although muscle length is typically the most important factor. While research data are limited, it appears that girls are more flexible than boys at all ages from 5 years of age forward.

During the adolescent growth spurt, bones grow in length without a concomitant increase in muscle development. Through this period, children often appear to move awkwardly and experience reduced ROM. As a result, they tend to perform activities in a more upright manner and their stride patterns and locomotor skills may actually deteriorate. While gentle stretching is advisable in this phase, some muscle tightness in the long muscles is expected. This tightness may continue throughout the period of rapid growth.

Trainability

Data on optimal stretching practices and trainability are lacking for both pre- and postpubertal populations. Children at young ages are pliable, but full ranges of motion are not normal in daily movement patterns, and the tissues typically exist in a shortened state.

TABLE 2. GENERAL STRENGTH TRAINING GUIDELINES FOR CHILDREN AND YOUTH

	PREPUBERTAL	POSTPUBERTAL
Frequency	2–3 times/week	3 times/week
Intensity	60%–70% 1 RM	60%–70% 1 RM
Upper Body	1 set, 13–15 reps	2 or more sets, 8–12 reps
Lower Body	1 set, 13–20 reps	2 or more sets, 8–15 reps
Full Body	initially 1 set (progress to 2 or 3) 8–10 exercises 30 minutes total	initially 2 sets (progress to 3) 10–12 exercises 45 minutes total
Variety	full body, machine, free weight or circuits nonweighted multijoint exercise	full body, machine or free weight weighted multijoint exercise
Notes	Program should be fun, well supervised and educational. Avoid maximum lifts.	Program should be well supervised and educational. Avoid jerk action and maximum lifts.

Flexibility can be modified by elongating any of the soft tissues surrounding the joint; these include the muscles, ligaments and joint capsule. Flexibility can also be improved by modifying the neural reflex mechanisms that protect the joints from large displacement forces. Of these options, elongating the muscle tissue is the most practical in children. Developing gross flexibility at joints during childhood through aggressive stretching practices and elongation of ligament and joint capsules is not recommended.

Program Design

Prepubertal children should be actively coached throughout a warm-up that includes slow, controlled movements through full ROM. Post-pubertal children should be taught to take responsibility for performing a dynamic warm-up that takes the joints through full ROM and prepares the body for activity. Developing proper warm-up and cooldown habits in these age groups is an essential component of their training. If well ingrained during childhood, these good habits will carry over into adult training practices.

Owing to rapid lever growth, children will typically have reduced ROM during the adolescent growth spurt. While gentle static stretching is important during this period, it is not the time to try for large gains in ROM, as this will further stress tendons and bony attachments that are already dealing with increased tension.

Secondary Fitness Characteristics

The secondary fitness characteristics include balance, linked multijoint power, speed, quickness, agility, movement skills and reaction skills. While the primary characteristics have been better studied in terms of impact on traditional measures of fitness and health, the secondary characteristics of fitness are an emerging area of emphasis in exercise programs.

Together, the secondary characteristics of fitness produce a "smart" body, enhancing the movement abilities needed for real-life actions, sport participation and, indeed, noncompetitive exercise. The goal is to improve the mind-muscle connection, making the muscles more compliant to the brain's commands, while enhancing intersegmental communication and linking the kinetic chain for more skillful movement. Training the secondary characteristics can also improve the primary fitness components, but as a byproduct of training for skillful movement.

During the prepubertal period of rapid neural development, children will continue to grow, experiencing gradual increases in both height and strength. During this stage, they become neurologically prepared for complex exercises in which they must explore how to coordinate required movements successfully.

Trainability

Since the most rapid rate of neural maturation is between 0 and 12 years of age, a key consideration is how to capitalize on the closing window of opportunity to train movement. Ironically, it is often during these ages that exercise is "dumbed down" with a focus on perceived safety. But children will respond favorably to complex and dynamic exercises that don't merely draw on the nervous system but challenge it, stimulating neuromuscular adaptations.

Training programs and physical education curricula targeting the secondary characteristics of fitness have been designed in response to the epidemiology of youth sport injuries. The highest incidence of emergency room visits for sport-related injuries occurs among 5- to 14-year-olds and then tapers gradually with age (Adirim & Cheng 2003). Children's lack of mature motor skills may place them at risk for injury. Without movement training intervention, children do not master complex motor skills until around ages 10–12 (Harris 2000).

Balance and body awareness are highly trainable. Balance skills improve rapidly in the first decade, but what underlies that expansion is not fully understood (Roncesvalles, Woollacott & Jensen 2001). Across all ages, balance training overloads a variety of "software" that the muscles rely on to detect, read, process and command biomechanical adjustments. The body uses somatosensory mechanisms to monitor changes in muscles, sending collected data to the spinal cord and back for quick, reflexive responses. Muscle spindles measure the rate of muscle lengthening; intrafusil muscle fibers run in parallel to extrafusil (EF) fibers, gauging changes in the length of the EF fibers; golgi tendon organs are well positioned at the musculotendinous junction to monitor tension in muscles; and mechanoreceptors detect deviations in joint position. Balance training can improve receptor sensitivity, the time it takes to complete the neural loop, and the accuracy of motor responses. Balance training impacts motor control systems and increased muscle activation toward whole-body stability (Versa-Garcia 2000).

Prepubertal and pubertal children will achieve only small training-induced biological alterations owing to lack of hormonal control; therefore, until puberty, the focus should be on skill acquisition rather than traditional physical conditioning (Katch 1983).

Program Design

To capitalize on the peak rate of neural maturation, skilled movement should be taught at a young age, if the muscular system can provide the forces necessary to support the activities. This does not imply sport-specific skill rehearsal; more important, it means movement skills—creating biomechanically efficient athleticism with foundational whole-body coordination.

Structured activities should include neural-based exercise targeting balance, movement skills, agility and reactivity. Together these will produce efficient movement patterns for future sport actions while also developing better movement abilities to train the primary fitness characteristics (aerobic running, cycling, swimming and dynamic lifts for muscular strength). Efficient movement skills are trained with multidirectional agility drills, laying the foundation for sport demands. Linear exercise—such as forward speed-based training—does not transfer to complex agility tasks, which require deceleration and direction change mechanics (Young, McDowell & Scarlett 2001).

Training in neural-based movement skills accelerates children's coordination—learned patterns they will draw on during the pubertal phase. The faster rate of bone (relative to muscular) growth during this period changes children's levers, mechanics and joint stability, impacting movement abilities and the efficacy of certain drills and exercise styles. Given that there is a temporary decline in coordination and balance during puberty, and that postpubertal children are more vulnerable to deceleration injury than prepubertal children because circulating androgens cause greater mass and speed (Harris 2000), safe training methods should be employed.

Pubertal program design must include transitional balance and deceleration training to prevent injuries from direction changes, when muscles are loading eccentrically from higher speed with less body control.

During the postpubertal stages, anaerobic conditioning, speed and quickness can be added to the program mix.

At all stages of development, the secondary characteristics of fitness do not require a high training volume, as exercises can be effectively integrated into dynamic warm-ups, fitness protocols and strength exercises.

In a subsequent article, we will outline practical exercises and program guidelines to help you navigate through the different phases of childhood, with specific training considerations for prepubertal, pubertal and postpubertal populations.

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