The Natural Development and Trainability of Plyometric Ability During Childhood

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SUMMARY

The inclusion of plyometrics within youth-based strength and conditioning programs is becoming more popular as a means to develop stretch-shortening cycle ability. Plyometric training adaptations have previously been reported for running velocity, power, agility, and running economy, and therefore, athletes should be exposed to this training modality at some point during their training program. However, some uncertainty still exists with regard to program design, especially when taking growth and maturational factors into account. This article reviews the current youth-based plyometric literature and provides a training progression model based around the long-term development of young athletes.

The Science of Plyometrics

Plyometrics refers to a training modality, mainly some form of jumping or rebounding, where an eccentric "stretching" of the muscle is rapidly terminated by a powerful isometric contraction, thus initiating a myotatic stretch reflex, which enhances the subsequent concentric action (41,48). The importance of plyometrics to a strength and conditioning program has previously been established, with positive training adaptations reported for force production (32), muscular power (45), running velocity (23), and running economy (19). Such biomotor abilities are underlined by a specific muscle pattern known as the stretch-shortening cycle (SSC), an intricate sequential combination of eccentric, isometric, and concentric muscle actions that promote an enhanced concentric force output (20). The SSC relies on elastic energy (5) and reflex muscle activity (22) mechanisms, both of which are believed to develop naturally throughout childhood and are also known to be sensitive to training.

Previously, the SSC has been categorized into fast and slow actions based on a ground contact threshold of 250 milliseconds (44). Fast SSC activities (<250 milliseconds) are prevalent in the stance phase during maximal sprinting (3), whereas slow SSC actions are evident in the performance of maximal vertical countermovement jumps. Although it has been suggested that slow SSC actions may enable greater force production because of increased contraction time (47), fast SSC actions promote greater movement speed via elastic energy usage and stretch reflex contributions (22). It is imperative that a coach and strength and conditioning specialist acknowledges the different categories of SSC actions and that athlete programs are designed with consideration given to the desired training form of SSC.

One way of ensuring that the athlete is being exposed to the correct training stimuli is by monitoring the reactive strength index (RSI), which is calculated by dividing the height jumped (millimeters) by the time spent in contact with the ground developing the required vertical forces (35). The measure has previously been viewed as a suitable means to prescribe and monitor plyometric intensity, by determining optimal drop jump height (15,35). Increases in drop height will promote improvements in RSI, as the SSC is sensitive to the magnitude and velocity of the eccentric stretch (7); however, excessive increases in intensity may promote prolonged ground contact times and reduced RSI measures.

KEY WORDS:
long-term athlete development; reactive strength index; stretch-shortening cycle; pediatric
Youth Plyometric Development

LONG-TERM ATHLETE DEVELOPMENT

Owing to the growing debate surrounding the physical and physiological development of youths, a number of long-term athletic development (LTAD) models have been developed in a bid to maximize athletic potential (1,49). Such models propose the existence of “windows of opportunity,” defined as unique periods within a child’s development where a heightened sensitivity to training adaptation is possible in response to the correct training stimulus (1,49). Based on research that has examined the natural development throughout childhood of various physical components, such as speed (40), strength (28,50), aerobic endurance (37), and muscular power (31), it is suggested that there exists two “windows of opportunity” for each characteristic (1). These typically include a prepubescent window incorporating age-related neuromuscular coordination developments and a circa- or postpubertal window linked to maturity-associated increases in muscle mass and circulating sex androgen concentrations (49).

Although it is accepted that the use of such models is better than none at all, a lack of longitudinal and empirical research has ensured that questions still remain as to the validity of such developmental pathways. Despite the existing issues regarding LTAD models, the identification of potential “windows of opportunity” has forced coaches to consider their approaches to youth athletic development.

Although there is existing evidence for strength, speed, and endurance, minimal research exists for plyometric development. It is suggested that the limited number of controlled studies that have used plyometric training in children is largely because of the possible misconceptions surrounding safety and ethical issues. Of the available literature, improvements resulting from plyometric programs have been reported for rebound jump height (36), agility and power (45), vertical jump performance (43,11), running velocity (23), and rate of force development (34).

Recent research has suggested the existence of periods of naturally occurring accelerated adaptation between the ages of 10 and 11 and between 12 and 13 for RSI in children (30), suggesting potential “windows of opportunity” for plyometric development. The authors did report worthwhile changes between various age groups for bilateral submaximal hopping, which promotes ground contact times indicative of fast SSC actions; however, the magnitudes of these changes were not deemed sufficiently large to assume that “periods of accelerated adaptation” were evident (30).

NATURAL DEVELOPMENT OF PLYOMETRIC ABILITY

Developmental trends for slow SSC ability have been reported indirectly from measures of squat and countermovement jump heights, with reported increases in vertical jump height as children become older (46,18). Improvements in motor coordination and more effective utilization of muscular power, possibly through increased muscle mass and rate coding, are proposed mechanisms underpinning such slow SSC development. Fast SSC, as represented by measures of leg stiffness during bilateral submaximal hopping, has also been shown to increase with age (30); however, the mechanisms for such development are less clear.

Plyometric ability is governed by effective neuromuscular function, which is the integration of both neural and muscular systems. Structural components that are likely to affect plyometric performance would include muscle-tendon size and architecture, tendon stiffness (the ability of the tendon to resist changes in length), and joint stiffness, defined as the ratio of the change in joint torque to joint angular displacement (24). Neural factors that may impact plyometric ability include motor unit recruitment, neural coordination (whole body, reciprocal, inter- and intramuscular), preactivation before ground contact, and stretch reflex responses immediately after ground contact. Such attributes are known to develop naturally throughout childhood and into adulthood, with younger children displaying more inhibitory mechanisms and a reduced neuromuscular efficiency (26), greater levels of antagonist activation immediately after ground contact (6), and lower stretch reflex responses than adults (17,38).

These studies would suggest that with age, muscle activation strategies transition from reactive, protective inhibition, to preparatory, performance-enhancing excitation. Because of these components showing evidence of natural development, it seems pertinent to suggest that they may be susceptible to further enhancement with exposure to the appropriate training stimulus. This is evidenced by the beneficial adaptation to performance markers (10) and a reduction of sports-related injuries (27,51) in a number of recently published youth-based training studies. Adaptations in agility and power (45), vertical jump height (11), rate of force development (34), rebound jump height (36), and running speed (23) have all been reported for youth populations in response to training programs inclusive of plyometric exercises.

Concerns related to damage to immature epiphyseal growth plates previously deemed plyometrics as an unsuitable training modality for children; however, it is apparent that very little research is available for promoting a “cause and effect” relationship between plyometrics and pediatric injury. The preventive measure endorsed commonly suggesting that as a prerequisite, children should be able to fully back squat 1.5 times their own body weight appears flawed, especially when considering that prepubertal children often participate unknowingly in low level plyometrics during their free play, namely, through some form of running, skipping, hopping, or jumping (10). Within such tasks, the extensors of the lower limbs are routinely subjected to the cyclical nature of fast SSC and arguably at lower exercise intensities than the prerequisite strength criterion would
promote. Therefore, the primary concern could be one of muscle damage and soreness; however, this should be avoidable with appropriate exercise prescription, correct supervision, and logical training progressions.

According to the recent National Strength and Conditioning Association (NSCA) position statement for youth resistance training (10), individuals instructing and supervising youth training sessions should possess a level of knowledge equal to a college degree, a recognized accredited status (e.g., NSCA Certified Strength and Conditioning Specialist or the United Kingdom Strength and Conditioning Association Accredited Strength and Conditioning Coach), and practical experience of working with children of different ages (10).

**IMPLICATIONS FOR PLYOMETRIC TRAINING**

Previous plyometric drill progressions have been reported in the literature (40), which provide strength and conditioning coaches with a logical approach to plyometric development. As with any form of exercise program, the variables of intensity, volume, frequency, repetition velocity, and recovery must be carefully monitored to ensure optimal athletic development while minimizing injury risk.

**TRAINING INTENSITY**

The intensity of a plyometric exercise refers to the amount of stress placed on the musculotendinous unit and is largely dependent on exercise selection (42). When considering appropriate training intensities for youths, it is essential that a child begins with low-intensity drills and gradually over time, advances to higher intensity drills (8). Only after sufficient experience and repeated demonstration of sound technique, should a child advance to higher intensity plyometric exercises. As with any form of exercise prescription, it is imperative that strength and conditioning coaches do not simply superimpose an adult-based program on children and must avoid treating children as “miniature adults” (14).

**TRAINING VOLUME**

Plyometric training volume has previously been discussed in relation to the total number of foot contacts performed during a single session (16). Authors have previously suggested that children begin with a single set of 6–10 repetitions, progressing up to 2–3 sets of 6–10 repetitions for both upper- and lower-body plyometrics (9). Therefore, total ground contacts for a child might range from 50 to 150 depending on their age, level of experience, and the training intensity, with initial lower loads for higher intensity exercises. However, it should be acknowledged that the quality of plyometric performance is more important than the total session volume. Owing to the large neural contribution inherent to plyometrics, it is suggested that strength and conditioning coaches make use of thresholds of performance variables such as ground contact time or RSI, to determine the end of a given set. For example, previous research has reported mean contact times of approximately 185 and 205 milliseconds for 13-year old boys, and 190 and 230 milliseconds for 16-year old males and females, during submaximal and maximal hopping exercises respectively (29), and such values could be used as “cut-off” points whereby a given set ceases when contact times go above such a threshold. However, it must be stressed that any performance threshold should be considered on an individual basis depending on the initial baseline performance of a child.

**TRAINING FREQUENCY**

Previous pediatric literature has proposed that children can perform plyometric exercises twice weekly on nonconsecutive days (8,9). Although there is a lack of evidence delineating an optimal training frequency, it is better to underestimate the child’s abilities than to provide excessive training exposure, which could ultimately lead to an overuse injury. Children are known to experience less muscle damage than adults, even when exercise intensity is controlled (33); therefore, using soreness to monitor training is deemed inappropriate. An alternative approach to assess athlete readiness could be to acquire a measure of ground contact time or RSI during submaximal hopping, which could reveal neural fatigue without placing excessive physical demands on the child. Previous research has revealed that exhaustive exercise involving SSC actions can reduce joint stiffness (25) and alter neuromuscular recruitment strategies (39) because of peripheral and metabolic fatigue. Consequently, the strength and conditioning coach should be aware of any additional physical conditioning that the child is engaged in, as additional training outside of the supervised program may produce a cumulative fatiguing effect that may result in injury, illness, or burnout (2).

**REPETITION VELOCITY**

Owing to the fact that successful plyometric performance is governed by effective SSC utilization, which in turn is mediated by both the magnitude and velocity of stretch (4,7), it is imperative that high repetition velocity is maintained. Clear and concise instructions should be given for any plyometric exercise, with a clear technical focus and motivational phrasing (e.g., “jump as high as possible, as fast as possible”) to maximize repetition velocity. Also, intermittent feedback from the strength and conditioning coach on performance thresholds such as contact time and RSI could increase athlete motivation and subsequent performance outcome (15).

Plyometrics require more intricate neural activation pathways than regular resistance exercises, and it is imperative that plyometric execution is reliant on both feedforward processes from the CNS before and feedback processes from proprioceptors during ground contact (48). To satisfy this requirement and maximize training adaptation, the number of sets and repetitions performed should be flexible, as opposed to the quality of repetition velocity during ground contact time.
RECOVERY

Despite the notion that children can often recover from repeated sets of moderate-intensity resistance training with less recovery time (13), plyometrics require longer rest periods to enable full neuromuscular recovery, maximize performance, and reduce injury risk (48). During the initial stages of the proposed model (Figure 1), rest intervals can range from 1 to 3 minutes (23); however, when training intensities are increased in stages 5 and 6 (in which athletes are entering adulthood), young athletes may require longer rest periods to enable optimal power development. It should be noted that the rest required specifically by a child might differ owing to individual variation; however, at all times, coaches should overestimate as opposed to underestimate the necessary rest to enable full recovery and maintenance of training intensity (8).

RECOMMENDATIONS

Although plyometric programming must be designed specific to an individual, below is a summary of the proposed guidelines for youth plyometrics:

1. Training intensity: should be based on eccentric loading, and at all times, children should progress from low-intensity to high-intensity exercises.
2. Training volume: children should use performance thresholds (e.g., ground contact time or RSI) to determine training volume; however, single sets of 6–10 repetitions, progressing to multiple sets of 6–10 repetitions as a general guideline is supported.
3. Training frequency: 2 sessions per week on nonconsecutive days.
4. Repetition velocity: use of performance thresholds (as above) to maximize motivation and performance quality.
5. Recovery: 60–180 seconds interset rest period for low level plyometrics; however, this may need to be increased when performing multiple plyometrics of a high eccentric loading nature.

SUGGESTED YOUTH-BASED PLYOMETRIC EXERCISE MODEL

Although a number of publications have suggested appropriate plyometric guidelines for children (9), it was deemed necessary to formalize a more comprehensive progression model (Figure 1), which corresponds with developmental stages aligned with the LTAD model (1). It is intended that this progression model will provide coaches with a more strategic approach to youth plyometric program design. Specifically, the model is designed to give coaches clear and simple guidelines to follow based on scientific theory and evidence, without being overly prescriptive, thus allowing coaches to implement the information in a way specific to the needs of individual athletes.

It is important to make clear that the model is designed for an athlete to enter the first stage at a young age, and that anyone entering at an older age should still complete the initial phase first, with a coach ensuring that appropriate
technical ability is demonstrated before the athlete progresses. The model contains approximated age ranges for each given stage, which are indicative of different maturational rates of men and women; however, regardless of gender or age, a child must develop mechanically efficient functional movement skills before attempting more complex plyometric drills.

The model proposes that athletes progress from one stage to another only once mastery is consistently displayed at the earlier stage. The model supposes that exercises should

Figure 2. (A) Bodyweight squats and (B) in-line lunges.
increase in intensity and decrease in volume as children are introduced to plyometrics of increasing eccentric loading. However, owing to the potential variation in biological development within a specified chronological age group and the lack of available research that distinguishes optimal plyometric training variables for youths, it must be noted that the progressions displayed in the model are not implicit for specific chronological age groups and that strength and conditioning coaches should use these guidelines with an awareness of individual variability in mind. It should also be highlighted that the model has been based on the interpretation of available scientific research, but longitudinal empirical research is required to establish its efficacy and effectiveness.

**STAGE 1: FUNDAMENTAL MOVEMENT SKILLS**

Although it has previously been suggested that children are able to begin plyometric training when they have the emotional maturity to listen to and follow instructions (8), the strength and conditioning coach should be satisfied that the child can demonstrate sound landing mechanics and competent basic movement patterns. Such fundamental movements should incorporate elements of agility, balance, and coordination and expose the child to an environment that develops kinesthetic and spatial awareness. Potential exercises are largely restricted to the imagination of the coach; however, such movement skills could include freestanding bodyweight squats and in-line lunges (Figure 2) or similar closed kinetic chain exercises requiring triple extension at the ankles, knees, and hips. Where possible, these exercises should be incorporated into games or deliberate play type activities, which should eliminate the boredom that can be displayed by children who inherently dislike monotonous forms of training (8).

**STAGE 2: LOW-INTENSITY PLYOMETRICS—JUMPING**

The next progression involves a range of jumping exercises, which require the child to perform on the spot jumps or vertical and horizontal standing jumps. These exercises typically involve the child jumping and landing bilaterally or unilaterally, thus highlighting the need for satisfactory fundamental movement skill mastery. In order for a child to minimize injury and maximize plyometric performance, it is suggested that they must display correct landing mechanics, including a heel-toe landing, supporting flexion at the triple extension sites, avoid excessive valgus knee displacement (Figure 3), as demonstrated in Figure 3, maintenance of lumbothoracic integrity at the point of ground contact, and coordination of the upper and lower limbs throughout the exercise.

**STAGE 3: MEDIUM-INTENSITY PLYOMETRICS 1–MULTIPLE BILATERAL HOPPING AND JUMPING**

Once the young athlete can execute jumping tasks proficiently, the
Figure 4. (A) Pogo stick hopping and (B) single-leg line hopping drills.
subsequent stage is hopping where an element of horizontal distance is introduced to the plyometric task. During this stage, children should be introduced to ground contact on the balls of their feet, only using a heel-toe foot strike when stopping. Exercises within this category might include “pogo stick hopping” (Figure 4A) and multiple countermovement jumps; however, where possible, multidirectional movements should be incorporated. This developmental phase should ensure movement characteristics indicative of true SSC behavior, requiring fast ground contact times (<250 milliseconds (44)), and a degree of preactivation, which require the child to use their lower limbs as “stiff springs.”

**STAGE 4: MEDIUM-INTENSITY PLYOMETRICS 2—BOX JUMPS**

Once a child has demonstrated competence at stages 1–3 and entered adolescence, they can move onto low-intensity box jumps (jumping onto and stepping down from a box), “obstacle” drills such as the use of hurdles, and multiple jumps. The aim of this stage is to increase eccentric loading, while maintaining both the speed of movement learnt in medium-intensity plyometrics 1 and the technical competence from the FMS and low-intensity plyometrics stages.

**STAGES 5 AND 6: HIGH-INTENSITY PLYOMETRICS**

The final 2 stages are for adolescents who are entering young adulthood.

**BOUNDING.** Such exercises would incorporate multidirectional, bilateral, or unilateral alternating foot contacts, whereby the objective is to cover maximum distance with minimal ground contact time, for example, single-leg line hopping (Figure 4B). This phase begins to place additional eccentric loading on the lower limb structures and should only be introduced to young athletes who are deemed able to tolerate such loading by their coach.

**DROPS.** Regardless of training experience, performers should be introduced to these stages at a low intensity (drop heights ≤20 cm), gradually intensifying the stretch load by increasing drop height, based on ground contact times or RSI measurements (35). The drop height should not be increased to an intensity that promotes an inhibitory protective strategy that reduces reflex activation (21). It is suggested that regular monitoring of performance variables are used to ensure that the plyometric intensity is not too great that a detrimental effect is experienced by the performer by way of increased ground contact times or decreased flight times and RSI.

**SUMMARY AND PRACTICAL APPLICATIONS**

The current article has highlighted that because of the natural adaptation of neural and muscular components, plyometric ability undergoes development throughout childhood and adolescence. Recent evidence would suggest that both slow SSC and fast SSC improve with age; however, such trends are nonlinear, with the possible existence of periods of accelerated adaptation. Incorporating the plyometric progression model and program guidelines proposed in the current article, strength and conditioning coaches should be able to plan and monitor youth-based plyometric training programs more effectively. This can be achieved with the training emphasis placed strictly on plyometric quality as opposed to plyometric quantity.

**REFERENCES**


