NSCA CEU QUIZ

Available at: https://www.nsca.com/certification/ceu-quizzes/

Taking A Long-Term Approach to the Development of Weightlifting Ability in Young Athletes

Stephanie J. Morris, MSc, CSCS,[1] Jon L. Oliver, PhD,[1,2] Jason S. Pedley, PhD,[1] G. Gregory Haff, PhD, CSCS*D,[3,4] and Rhodri S. Lloyd, PhD, CSCS*D[1,2,5]

[1]Youth Physical Development Centre, Cardiff School of Sport and Health Sciences, Cardiff Metropolitan University, Cardiff, United Kingdom; [2]Sport Performance Research Institute, New Zealand (SPRINZ), AUT University, Auckland, New Zealand; [3]School of Medical and Health Sciences, Edith Cowan University, Western Australia, Australia; [4]Directorate of Psychology and Sport, University of Salford, Salford, United Kingdom; and [5]Centre for Sport Science and Human Performance, Waikato Institute of Technology, Hamilton, New Zealand

ABSTRACT

Despite previous misconceptions, youth participation in weightlifting is now recognized as safe and beneficial when delivered, programed, and monitored by a qualified professional. This article explores teaching progressions to help coaches periodize weightlifting training for young or novice athletes, with consideration to the theoretical concepts underpinning long-term athletic development. It is hoped that the structured and progressive guidelines presented in the current article will help coaches develop the weightlifting performance of their young athletes in a safe and effective manner.

INTRODUCTION

Weightlifting is a sport where the snatch and the clean and jerk are contested. In weightlifting competitions, athletes have 3 attempts to lift the maximum amount of weight in both lifts; with athletes placing within their respective bodyweight class as determined by the sum of the highest completed lift for both movements. Some of the highest absolute and relative peak power outputs reported in the literature have been achieved in the weightlifting movements, with national lifters producing a relative peak power output of 55.8 Watts/kg (6981 W/125 kg) during the second pull of the clean (54). Power outputs for athletes of similar bodyweights have been found to be 2 to 3 times higher in the weightlifting movements than in squats and deadlifts (55). Maximum strength, identified as squat one repetition maximum (1RM), and peak power output derived from vertical jumping have been found to strongly correlate with weightlifting performance among national-level male and female lifters (21). Such findings highlight the importance of maximal force and rate of force development for weightlifting performance.

Address correspondence to Stephanie J. Morris, stmoris@cardiffmet.ac.uk.

THE TRANSFERENCE OF WEIGHTLIFTING

Although the superior power output of weightlifters may be related to sport-selection factors, it is also likely to be the result of long-term adaptations to the type of training programs that they are exposed to (51,53,68). Considering the high strength and power expression during the competitive weightlifting movements (51,53,70), weightlifting training methods are commonly used to develop and improve physical qualities required in many sports (59,64,67,71). Such benefits are especially transferable to explosive movements such as sprinting and jumping (21). Furthermore, performance of

KEY WORDS:

snatch; clean and jerk; motor learning; resistance training; novice

the snatch, clean and jerk, and derivative lifts (i.e., clean and snatch shrug, clean and snatch pull from various positions, power clean and snatch, and push jerk) typically use moderate to high external loads, with minimal to no deceleration in the propulsion phase of the movements (52,68). In contrast to typical resistance training exercises, the ballistic nature of these movements is advantageous to strength-speed adaptations, which are beneficial for all sports hence its popularity as a training method; for example, 95% of National Basketball Association (118), 88% of National Football League (38), and 100% of National Hockey League (39) strength and conditioning coaches reported using weightlifting as part of training. In addition to the development of force-generating capacities, the high skill complexity required for the weightlifting exercises also facilitates improvements in motor control, improving coordination of activation of muscle groups and motor units (45,61). These adaptations have the potential to also aid in the development of more complex sports movements, which is why the inclusion of weightlifting in long-term athletic development (LTAD) programs could also benefit coaches in other sports who adopt weightlifting as a training mode for their athletes. At the present time, long-term approaches to athlete physical development seem especially important, given the declining levels of muscular strength and overall habitual physical activity in young individuals (113).

INTRODUCING WEIGHTLIFTING TO YOUNG AND NOVICE ATHLETES

Achieving weightlifting expertise requires a systematic approach to develop both the skills and strength to complete complex lifts under heavy loads. Although general models of LTAD exist (6,49,87) together with sport-specific (15,19,86) and training mode-specific (35,36) models, there is little published material regarding how to approach the long-term development of weightlifting ability from a young age.

Childhood represents the developmental period of life from the end of infancy to the beginning of adolescence, referring generally to children up to the age of 11 and 13 years in girls and boys, respectively (83,91). The term *adolescence* refers to a period of life between childhood and adulthood, when secondary sex characteristics are developed. Although adolescence is a more difficult period to define in terms of chronological age due to differential maturation rates, girls 12–18 years and boys 14–18 years are generally considered adolescents (83). The period of childhood seems to be the optimal time to develop coordination and movement competency because neuromuscular adaptation is heightened due to greater levels of neural plasticity in the developing brain (22). Based upon previous meta-analytical data, prepubertal and early-pubertal youth can achieve approximately 50% greater training-induced gains in motor skills in response to resistance training interventions compared to adolescents (11). More recently, research has identified that less mature athletes may have an increased sensitivity to adaptations in motor control after neuromuscular training (34). Cumulatively, these findings indicate that athletes should ideally be introduced to weightlifting-based training methods during childhood, before the adolescent growth spurt, learning the weightlifting movements while neuroplasticity is at its highest.

Performance improvements have been found in young athletes, representing both children and adolescents (83), after short-term weightlifting interventions (23,64,105). Improvements in performance were similar when comparing the effect of resistance training, or a combined resistance and weightlifting programs for young athletes, equally matched in training dose (105). Replacing half of the training time with weightlifting exercises resulted in similar gains in athletic performance, but also enabled the young athletes to acquire highly transferable weightlifting movement skills (105). Childhood may be the best time to introduce young athletes to weightlifting-based training because neuroplasticity is high, making it the ideal time to learn and refine motor control strategies that may induce adaptations beneficial to performance and later assist in the acquisition of more complex movement skills (33,57,96).

Although weightlifting exercises and their derivatives have shown to positively influence a number of key performance variables (59,64,67,71), some coaches are still reluctant to introduce novice athletes to weightlifting-based training methods, often suggesting that teaching weightlifting movements is overly time-consuming due to the technical demands of the lifts (65). Contrastingly, technique improvements from a short-term weightlifting intervention have been found in athletes naive to weightlifting, after performing 2 training sessions per week for 4-weeks (64,71). Furthermore, many coaches may use loaded jumps as an alternative to weightlifting exercises due to the comparably lower skill demand but similar effectiveness for improving explosive performance (104). Importantly, however, loaded jump training does not elicit comparable adaptations in an athlete's eccentric strength and ability to rapidly accept force, as developed from the catch phases of the weightlifting movements (27,29). Although the context of each athletic development program is unique to the environment and personnel within that environment, a common goal of LTAD is to promote habitual improvements in athleticism over time to improve performance, reduce injury risk, and enhance health and wellbeing (41). Short-term investment in technical development of weightlifting movements, with ongoing technical refinement and weightlifting training, will pay dividends later in a young athlete's career; therefore, qualified practitioners should be encouraged to integrate relevant weightlifting training methods into their programs.

When individuals are at an age at which they can follow coaching instructions and handle the attention demands of a training program (99), weightlifting techniques should be a focus of early interventions, to acquire competent technical skill in the early stages of development (2). Lifting maximal loads should not be a training goal as the athlete develops weightlifting literacy. Errors in technique may become engrained, making attempts to modify technique at later stages more challenging, if not impossible; given that performance may temporarily deteriorate when the athlete changes technique, this correction can be frustrating for the athlete and coach, with the potential to limit future development (92). From a training perspective, if an athlete acquires a sound and robust technique at an early stage, there will be more opportunities to use progressive overload stimuli (e.g., heavier loads) to target intended training effects, such as strength-speed capacity (128). In addition, technique when performing the weightlifting movements may affect training adaptations. Movement positioning and timing, or "lifting technique," can influence an athlete's ability to produce force, especially relevant in weightlifting, given the importance of the magnitude and temporal sequencing of force production and absorption in successful lifts (40,52,89,101). Poor technique therefore has the potential to impair force production and subsequent improvements in motor control, coordination, muscle activation, and motor unit recruitment (45,61).

Correct technique could also reduce injury risk, with poor technique often referenced as an extrinsic risk factor associated with injury (73,76). Despite previous concerns around the injury risk of weightlifting and misconceptions that weightlifting is unsafe, research has shown weightlifting to be a low risk sport in both youth and adult populations (1,17,100), with evidence to suggest weightlifting may also elicit positive adaptations in bones, ligaments, and tendons along with improved movement competency and strength that are beneficial for reducing injury risk (60,86,100). However, poor technique during the lifts could lead to athletes being exposed to undesirable and potentially dangerous positions under load, increasing the risk of injury. Even with low resistance, if the athlete is allowed to perform weightlifting movements with poor technique, then the risk of injury will be amplified as resistance is increased. This notion underlines the importance of qualified professionals being responsible for the design, implementation, and coaching of weightlifting movements to young athletes (82,83,88).

To ensure proper technique is established in the early stages of development, coaches should follow appropriate coaching progressions to help implement a structured and systematic approach that progresses logically based on technical competency, to ensure athletes can learn the movements in a timely, yet effective, manner. Consideration of training focus, exercise selection, and training prescription for LTAD may help coaches to periodize training in a more sequential and progressive manor to facilitate the development of optimal technique and overall wellness as well as reducing injury risk (73). Therefore, the purpose of this article is to present an LTAD model for the development of weightlifting ability. The progression scheme in this article presents guidelines applicable for all athletes, including those not yet involved in competitive sport. The model may be applicable to young athletes participating in weightlifting as a sport, however, importantly does not advocate early specialization and would encourage young athletes to engage in a variety of sports concurrent to the development of weightlifting competency to the effect that total training load across all activities should be monitored and training objectives aligned.

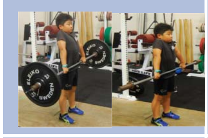
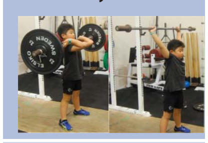
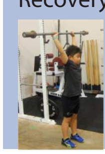
TEACHING WEIGHTLIFTING MOVEMENTS: KEY PHASES

To develop weightlifting technical competency, phases of each lift need to be identified to make learning these complex, multijoint movements easier. Breaking the full lifts down into key phases, referred to as movement "*chunking*," may also help coaches to identifying movement errors, allowing training prescription to be more specific in targeting individual deficiencies. Based upon the theory of "*chunking*," youth and novice athletes can work on these components in isolation, but then string the individual exercises together to create a sequenced movement pattern (60). Breaking the movement down into key phases can also be beneficial for devising fun, competitive games to create an enjoyable environment and maintain athlete interest; for example, athletes could race a partner to drop into the catch position on a command. Table 1 identifies the key phases in the clean and jerk and snatch.

LONG-TERM DEVELOPMENT OF WEIGHTLIFTING PERFORMANCE

Given the lack of available literature on coaching weightlifting movements to young athletes, the present review introduces a progression scheme that is aimed at promoting a systematic long-term approach (Figure 1). The progression scheme offers a comprehensive approach to the developmental stages for weightlifting training, from beginner to advanced, identifying the training focus and coaching considerations at each stage. For optimal skill acquisition, performance and injury prevention, training at all stages should consider the simultaneous development of movement skills (i.e., competency, autonomy, and refinement) and physical capacities (i.e., motor control and bodyweight management, basic strength, maximum strength, and explosive strength); the prescription and exercise selection should then be manipulated accordingly. It is important to note that the progression stages are specific to each segment, and some athletes will move through the progressions within the segment at

Table 1
Phases of the clean and jerk and snatch

Phase	Clean and jerk	Snatch
1st pull 	From lifting the barbell off the floor to a position in which the barbell is immediately at the patella	From lifting the barbell off the floor to a position in which the barbell is immediately at the patella
Transition 	From a position in which the barbell is immediately at the patella to a position in which the barbell is positioned midthigh	From a position in which the barbell is immediately at the patella to a position in which the barbell is positioned at the upper thigh
2nd Pull 	From a position in which the barbell is positioned at the midthigh, the athlete should extend at the hips, knees, and ankles moving the bar to a position of maximal barbell height	From a position in which the barbell is positioned at the upper thigh, the athlete should extend at the hips, knees, and ankles moving the bar to a position of maximal barbell height
Catch 	From a position of maximal barbell height to a position in which the bar is caught resting on the anterior deltoids, in a front-squat position	From a position of maximal barbell height to a position in which the bar is caught above head in an overhead-squat position
Recovery 	From a position in which the bar is caught resting on the anterior deltoids to a standing position with the bar remaining in a front-rack position	From a position in which the bar is caught above head in an overhead-squat position to a standing position with the bar remaining above head.
Dip 	From standing, with the bar in a front-rack position to a quarter-squat position with the bar remaining in a front-rack position	
Drive 	From a quarter-squat position with the bar remaining in a front-rack position to a position of maximal barbell height, with the athlete extending at the hips, knees, and ankles	
Catch 	From a position of maximal barbell height to a position in which the bar is caught above head in a split-stance position	
Recovery 	From a position in which the bar is caught above head in a split-stance position to a standing position with the bar remaining above head.	

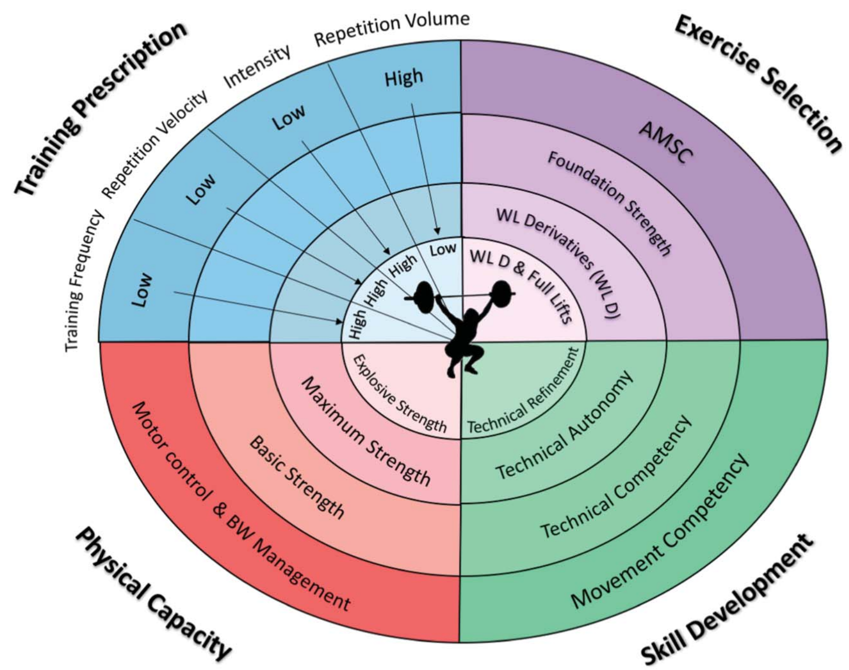


Figure 1. Long-term development of weightlifting performance progression scheme (BW = bodyweight). Novice athletes are introduced at the outside circle of the model, and training progresses inward in all directions; progressing from the beginner stage, to novice, intermediate, and advanced stages indicative of a reduced color depth. Progression through each segment should be based on individual ability, with progression rates unlikely to be uniform across all segments.

different rates. Progression through each segment should be based on individual ability, with progression rates unlikely to be uniform across all segments. For example, training for an athlete who has good levels of basic strength and movement competency in the athletic motor skill competencies (AMSC) (defined as the foundational movements that underpin all athletic movements (108)), but has had no previous weightlifting exposure should prioritize weightlifting technical development alongside training to improve maximal strength. Although the present review offers only an approach to the long-term development of weightlifting abilities, the importance of a holistic approach to LTAD should not be negated, and additional exploratory play, training, and sports participation should be implemented concurrently to develop additional physical qualities such as speed, agility, endurance, metabolic conditioning, and sport-specific skills (87). Likewise, although this review focuses primarily on the importance of physical development, the emotional and psychosocial aspects of LTAD should not be overlooked.

Moving from the outer to inner circles, the 4 circles indicate the different stages of development, progressing from beginner, to novice, intermediate, and advanced. For example, training for an athlete with no prior weightlifting or resistance training experience should start in alignment with the outside circle of the progression scheme and progress inward. As shown, training at all stages should consider the development of movement skill and physical capacities. For example, training for a beginner across all segments should prioritize the development of movement competency while synonymously improving motor control and bodyweight management.

The prepubertal stage of maturation is typically indicative of higher neural plasticity (87), suggesting a heightened sensitivity to motor control and coordination training. Therefore, athletes should ideally be introduced to weightlifting development during childhood. Although stage of maturation should be considered, more importantly technical competency should dictate where on the progression scheme an athlete is introduced. For an ideal scenario in which the athlete begins their weightlifting development in early childhood, the outside circle in the progression scheme is representative of the training at this stage (Figure 1). Likewise, the process can be mirrored for older, less experienced youth athletes. For example, in situations where an athlete is first introduced to weightlifting during late adolescence, irrespective of maturity status, the athlete should start in the outside circle of the progression scheme on the weightlifting skill development segment, progressing inward on this segment at a rate dependent on their technical competency.

Exercise selection and training prescription may be dictated by weightlifting competency; during the early stages of LTAD, exercises should be selected predominantly to help the athlete correctly perform the movement skills. For example, training for the beginner is likely to include predominantly AMSC, to develop a foundation upon which to build more sport-specific skills, with a higher repetition volume but lower intensity, repetition velocity, and training frequency. Once the athlete has achieved competency, exercise selection and training prescription may be dictated by technical errors but also the training adaptation required to address physical deficiencies. Importantly, just because an athlete has progressed inward on a segment does not mean that the previous quality will not be included within their training; rather it becomes less of a key focus within the training program. For example, athletes will still need to maintain maximum strength capacities even when the

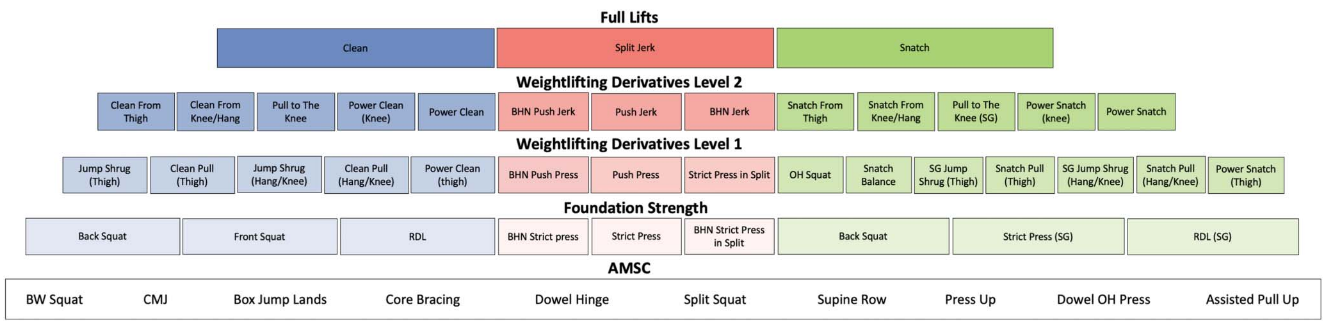


Figure 2. Clean, jerk, and snatch, and exercise progressions (RDL = Romanian deadlift; BHN = behind neck; OH = overhead; CMJ = countermovement jump; BW = bodyweight; SG = snatch grip). Exercises are ordered by increasing movement complexity and increasing technical specificity from the bottom of the pyramid working upward as indicated by increased color depth; progressing upward from AMSC, to foundation strength, weightlifting derivatives level 1, weightlifting derivatives level 2, and full lifts.

priority has shifted to the development of explosive strength.

A "*top down*" approach for teaching the weightlifting movements is frequently recommended in coaching guidelines (35,36,86). In this approach, the distinct phases in the clean and snatch (Table 1) are taught in reverse order to their performance in the whole movements; first teaching the catch position, then hang derivatives inclusive of the transition and second pull, first pull, and then the whole movement, with the athlete often learning multiple exercises concurrently at each stage. This approach is logical and safe, ensuring athletes can perform the overhead squat, for example, before expecting them to perform a hang snatch in which they have to catch the bar in the overhead squat position. In addition, the top down approach is in alignment with the motor learning concept known as reverse or backward chaining (24), demonstrated to be an effective method for teaching motor skills (37,117). Based on this approach, Figure 2 presents a progression pyramid to aid in the learning of full snatch and clean and jerk movements. To ensure a time-efficient approach to skill acquisition, the exercises follow the top down approach but also order exercises by increasing movement complexity, from the bottom of the pyramid working upward. The coach must ensure the athlete is competent in the AMSC first; from here, competence in the weightlifting catch positions (front squat, overhead squat, and press in the split position) should be achieved. Exercises progress upward from AMSC, to foundation strength exercises that serve as foundations for the increasingly more specific weightlifting movements, to then weightlifting derivatives level 1, weightlifting derivatives level 2, and full lifts.

TRAINING FOCUS

BEGINNER

As a prerequisite to training, athletes must demonstrate the ability to follow coaching instructions and handle the attention demands of a training program, which typically occurs around the age of 7 or 8 years (99). Before learning the weightlifting movements or attempting to perform any of the movements and their associated derivatives, a young and/or inexperienced athlete must also demonstrate their ability to perform simpler, prerequisite movements. The focus in the beginner stage should therefore be the development of AMSC (87,88), the foundation level of the progression pyramid (Figure 2), to establish underpinning qualities from which specific weightlifting technical competency can be developed. Such an approach aims to avoid any motor proficiency barriers manifesting as the exercise complexity increases.

Bilateral lower-body movements, and jumping and rebounding movements are identified categories of AMSC (88). Hip hinging, squatting, and jumping are all key movement phases in the weightlifting movements themselves, with the hang positions necessitating a Romanian deadlift (RDL) movement, the triple extension movement in the second pull mimicking the explosive hip and knee joint extension required for a jump, and the squat position being the movement required for the catch position in the clean and snatch movements. Hence, these AMSC should be deemed as essential prerequisites to performance of the clean and snatch movements. Likewise, the athlete should develop movement competency in lower-body unilateral exercises such as the split squat, with the movement replicating similar positions to those required in the split jerk movement.

The catch phases of the weightlifting movements demand high force absorption in a short duration of time (29), requiring high levels of eccentric strength. In accordance with plyometric progression models, exercise selection should progress from lower to higher eccentric loads (84). Therefore, in the foundation stages, it is important to develop sufficient strength during body management tasks such as the AMSC before progressing into the weightlifting movements. The correct landing mechanics, which will be mimicked in the catch position of the snatch and clean and jerk, should first be learned in low eccentric load conditions, such as a jump to box, to prioritize the correct positions, progressing then onto higher eccentrically demanding movements such as a countermovement jump and box drop landings thereafter (84). From here, the athlete has learned the rudimentary skills to progress onto more weightlifting specific movements learned at the novice stage, such as barbell jump shrugs or pulls.

The overhead demands of the catch position for both the snatch and jerk should also be considered during this stage. Before any vertical pressing movements, horizontal pressing movements (e.g., press up) should first be mastered to teach the athlete correct scapulohumeral rhythm and core bracing, while also developing upper-body strength. These are key physical qualities that are needed when pressing a bar overhead, whereas the incorporation of pulling movements in the horizontal position ensures an agonist-antagonist balance.

Importantly, these movements need not be regarded as the starting point for any athlete, with regressions and progressions being available for all the movements (108). Before teaching the bodyweight squat, for example, the coach may first ensure the athlete is competent at performing an assisted squat, in which the athlete can use external assistance (e.g., resistance band) to reduce the load and better find a balanced position throughout the movement. Likewise, before teaching the press up, the coach may first ensure the athlete can perform an isometric press up hold to build positional awareness and strength in the end position of the movement, progressing to a hands-raised press up, which has a lower intensity than the full press up.

The athlete may first learn the AMSC through less structured, more exploratory training using "animal or superhero shapes," before progressing on to more structured versions of these movements with increased load. For example, learning to "jump and land on lily pads as a frog" in exploratory animal shape games before more structured countermovement jump and drop land exercises to reinforce takeoff and landing mechanics (85). The importance of fun practices to keep athletes challenged and engaged for the long term should not be underestimated. Therefore, the athlete may also be exposed to fun-based competitions and playground-based games that incorporate the AMSC, such as obstacles courses or "tag." These games-based activities may provide an element of social interaction, important in the athlete's developmental years (119). In addition, the element of competition has the potential to increase athlete enjoyment, effort, and performance (30). Introducing competition in this subtle manner early in the athlete's development may help to reduce the prevalence of larger competition pressures that occur later in their development eliciting distress and being perceived as threatening (50). The prepubertal stage of maturation is typically indicative of lower strength and power expressions but higher mobility and neural plasticity (87). Ideally, children should therefore enter an LTAD program at this stage of maturation to take advantage of the naturally occurring adaptations, with an aim of learning and engraining underpinning movement skills over a full range of movement, concurrent to adaptations in motor control and strength. Despite compelling evidence advocating resistance training as safe and effective in youth populations (41,83), many parents, sports coaches, and health care professionals may still believe the misconception that youth resistance training is unsafe and harmful. As a result, the qualified professional coaching the training program may need to implement strategies to dispel such myths and adopt a proactive approach to help parents and professionals understand the importance of this type of training early in life to optimize adaptations. Such strategies could include parents' evenings, which will give parents and sports coaches an opportunity to ask questions about the training and allow the coach to present and explain existing evidence on the benefits and safety of youth resistance training and weightlifting. Similarly, poster handouts or information sheets, which should present evidence on the benefits and safety of youth resistance training in an easily digestible format using nontechnical language and visuals, and open coaching sessions in which parents can come and watch the coaching sessions, demonstrating coaching transparency are viable means of education.

NOVICE

Once the athlete is proficient at performing the prerequisite movements, they will need to progress into movement skills that more closely resemble the weightlifting movements. The early stages of learning weightlifting techniques are likely to present characteristics representative of the cognitive stage of motor learning (47), with a high movement variability and large, but often inconsistent, improvements in performance. During this stage, the athlete is trying to process information in an attempt to cognitively understand the requirements and parameters of the new movement task (47).

The *degrees of freedom* concept in motor learning suggests that there are multiple ways in which muscles, joints, and limb segments may vary in position and movement to achieve the same goal (12). Expanding on this concept, Newell's dynamic systems theory proposes that movement is produced from the interaction of multiple subsystems within the person, task, and environment, and motor system degrees of freedom can reorganize over time in the long-term development of a movement skill (102). Dynamic systems theory suggests that during this early stage of learning, the athlete is creating a coordinative structure; the subsystems come together and interact in a specific way to produce the most efficient, task-specific, movement solution that would not be not obtainable by any of the subsystems alone. The appropriate relative motions among relevant muscles, joints, and limb segments are assembled to satisfy the task constraints (102).

As such, the use of weightlifting derivatives or movement "*chunking*," rather than the full lifts that demand whole body coordination, may be beneficial at this early stage of movement acquisition to simplify the task and reduce information load (13). At this stage, learning the exercises from the foundation strength level on the progression pyramid should be prioritized (Figure 2). Teaching the positions relevant to the catch phases of the lifts should be the priority, learning the front squat and the overhead pressing positions relevant to the jerk and snatch catch positions. When considering exercise selection and intensity, selecting an exercise with the optimal level of movement challenge and load should be carefully considered by a coach, as a difficulty level that is too high or too low could affect athlete motivation, enjoyment, and performance (20). The coach may prefer to first teach the overhead movements from a behind the neck position, before progressing to in front to reduce potential issues related to the barbell being close to the face of the young athlete who is learning weightlifting-based movements, promote a better overhead position, and reduce anterior-posterior postural sway (60). A wooden dowel or PVC piping may first be used instead of a barbell. The lighter load of the PVC pipe will allow the athlete to practice and establish the correct techniques, with a lower injury risk if the athlete was to demonstrate poor technique. Once technical competency has been demonstrated, they may progress to a light barbell (5–10 kg) and then to an appropriate weightlifting bar (males 20 kg and females 15 kg).

Given the high-power outputs and key contribution of the second pull phase in the weightlifting movements (21,27,51,69,121), but low movement complexity, teaching the "pulling" element of the movement skill concurrent to the more challenging catch positions may be advantageous (90). Introducing the clean and snatch from a midthigh or upper-thigh position, respectively, allows the technique to be simplified while still taking advantage of the adaptations that can be gained from the second pull phase (65). Specifically, the barbell jump shrug exercise has been shown to elicit timely training improvements in power, encouraging the athlete to achieve full extension in the second pull movement by a using familiar jump exercise, while teaching a low-complexity weightlifting movement (27,121,122). Although the jump shrug is a good developmental exercise, it should be used with caution because it has the potential to result in an overexaggerated jumping motion, which can cause issues for the youth athlete when they transition into weightlifting movements that require the athlete to catch the bar in a fixed position overhead or on the anterior deltoid. A viable alternative to using the jump shrug is to use the pull from the mid to upper thigh because it requires the young athlete to maintain better postural control while working to create an effective knee and hip extension, which leads into a shrugging motion. From a progression perspective, it may be useful to first start with the pulling motions and only use the jump shrug with athletes who are unable demonstrate an appropriate triple extension when progressing from the pull into a weightlifting movement that requires the barbell to be caught overhead or on the anterior deltoid.

This approach limits the movement solutions available to the athlete, removing the contribution from multiple joint segments, helping them to best identify a more optimal movement solution (12,124). However, deconstructing full movements into smaller phases for skill acquisition has been suggested to lead to the performance of abstract movements only partially relevant to the end skill (62). The coach should ensure the weightlifting movements are not deconstructed too excessively; therefore, although Figure 2 presents a plethora of exercises that may be used to progressively teach the weightlifting movements, it is likely the best coaching approaches will not include all these exercises. For example, similarities in kinetics and kinematics in the hang clean exercise in comparison to the clean (28) may suggest a close resemblance in perceptual information between the movements, implying in this instance that the deconstructed skill is similar to the full lift. Many of the weightlifting derivatives and variations consist of the key phases of the weightlifting movements, with the hang clean, for example, comprising the transition, second pull, and catch phases (Table 1). Importantly, to prevent excessive deconstruction, the coach must consider whether the exercise is a task simplification; in which different components of the complex coordination patterns are learned in tandem, allowing information and movements to remain coupled throughout (111), or whether learning the new movement may teach performance of abstract movements only partially relevant to the key phases in the full lift (62). The later movements may be used as corrective exercises to address athletes' weaknesses; however, they may be less appropriate when the primary aim is to ensure movements transfer to the full lifts. Therefore, coaches may choose to use abstract movement in a training program alongside task simplified movements to develop transferable weightlifting movement skills. For example, jump shrug exercises may be used in conjunction with cleans from the knee.

In an ideal scenario where the athlete begins their training during childhood, the athlete is likely to be in the circumpubertal stage of maturation when they reach the novice stage of the progression scheme. The circumpubertal stage of maturation is indicative of a period of "adolescent awkwardness" with potential breakdowns in motor coordination as a consequence of learning to use longer limbs (86).

Research has found that 76% of girls and 90% of boys who experience this growth spurt show a clear impairment of coordination (66). A decrease in sport-specific performance as a result of the growth spurt is found to be more prevalent in movements that demand higher coordination, with research showing a higher performance regression evident in a somersault movement compared to a headstand (66). Should an athlete demonstrate impaired coordination at this stage of development, a coach should consider primarily prescribing the weightlifting derivatives, which have a reduced complexity in comparison to the full movements and typically require a reduction in load. The circumpubertal growth spurt may also be accompanied by a reduction in mobility (86). When reinforcing movement technique, practitioners should therefore ensure athletes continue to use a full range of movement and may consider supplementing training with additional mobility exercises to address any limitations.

To ensure the investment in time continues to elicit improvements in performance, there is the need for integration of skill and physical capacity development, rather than considering the 2 as separate entities. Such an approach also helps to ensure the prerequisite movements for more complex movement tasks are achieved in an efficient training order and a delayed training adaptation in weaker, inexperienced athletes is prevented (64). Therefore, concurrent to the focus of weightlifting technique development during the novice stage, training focus should also be given to the development of basic strength. To continue progressively developing strength qualities, supplementary resistance training progressing from bodyweight to movements with external load should be used. For example, to develop bilateral strength development, initial prescription could involve a bodyweight squat with training dowel, before advancing to a barbell front or back squat, with the ultimate goal of developing the underpinning muscle strength required to catch the bar under high load as required in the weightlifting movements. The athlete will first be challenged to find and hold the correct front squat position, and once competent, will be challenged to repeat the squat movement under progressively increasing loads. This developmental approach will also help to highlight if the athlete has any weaknesses or muscle imbalances, which should be appropriately addressed with supplementary corrective exercises.

To gain exposure to the tactics relevant to the competition of weightlifting, the athlete may gain competition experience at this stage. Importantly, however, the rush to compete should not compromise the athlete's long-term development of athleticism and strength. Therefore, for novice athletes of any age wishing to compete in weightlifting competitions, scoring or athlete placing should be focused solely on technical competency in the weightlifting movements or learned derivatives. Such an approach is supported by modified rules for youth lifters in weightlifting competitions, with technical proficiency and not load lifted, being the emphasis until the age of 13 years (78). Similarly, in instances where the athlete is a novice in the weightlifting movements, yet older than 13 years of age, coaches should consider including informal competitions within the training program, where athletes are scored on technical proficiency. Coaches should insist this type of competition is performed before allowing them to enter competitions in which they are scored by load lifted and prematurely demanded to lift higher loads.

INTERMEDIATE

During this stage of motor learning, the athlete works to control or vary the parameters of the basic coordinative structure, enhancing the flexibility of their weightlifting movement skills (102). The training focus at this stage is therefore technical autonomy, which aims to promote an enhanced ability to manipulate movement strategies to achieve the desired performance outcome and increase the reliability of technical execution in the weightlifting movements.

At this stage, exercises from the weightlifting derivatives level 1 up to the full lifts on the progression pyramid may be learned (Figure 2). Some coaching bodies (e.g., UKSCA) may advocate specifically teaching and segmentally practicing the transition phase, often referred to as the double knee bend; however, others have questioned whether it is necessary, with research to suggest this may need not be specifically taught providing the appropriate teaching progressions are mastered (56,107). Irrespective of coach preference, ensuring the athlete can transition effectively and perform the second pull phases are of key importance at this stage. The exercises may therefore now include lifts performed from the hang position, a position representative of the end of the first pull and start of the transition (Table 1). Strength in this motion will have been developed before this through the use of RDLs, which may now be incorporated into movement sequences, such as an RDL coupled with a shrug (i.e., pull from the knee). The hang shrug movement or pulls from hang may also be introduced at this stage, teaching the athlete both the transition and second pull phases of the weightlifting movements. Relevant to the snatch, the drop snatch or snatch balance movements may be taught at this stage, which encourage the athlete to rapidly drop under the barbell to catch the bar overhead. This ability is important for the snatch lift, given that research has shown that skilled lifters demonstrate a decreased barbell height in the catch position in comparison to lesser skilled lifters (58), indicative of dropping under the bar rather than pulling the barbell to a higher height, irrespective of barbell load.

As the athlete progresses and exercises increase in movement complexity and eccentric demand, the catch phases of the lift may be added to the transition and second pull phases of the weightlifting movements. As such, the hang clean and hang snatch may be performed, in which the athlete starts the movement from a position with the bar above the knee and finishes in the catch position. Coaches may prefer to teach the hang power snatch and hang power clean variations of the lift first. From here, coaches are likely to progress then onto power clean and front squat or power snatch and overhead squat in sequence, to develop awareness and strength in the catch positions. The use of combination lifts such as these have been classically used as tools for developing the key movement patterns associated with the clean and snatch.

Once the athlete is able to perform all the derivative movements with correct technique, they can then proceed to attempting to perform the full lifts; the clean, jerk, and snatch. The increased degrees of freedom in these exercises are indicative of progression, demanding the athlete to reorganize around a new movement solution (112). After this increased movement complexity, heightened movement variability may be expected at first, indicative of instability in the movement behavior (110). Variability may increase until a specific critical point, in which the system switches to a new, more stable movement pattern. The coach should therefore not be concerned with the initially heightened movement variability, given its importance in motor learning.

By this stage, athletes should be competent in the AMSC, and basic strength should already be established. The AMSC are likely to remain in the training program to ensure maintenance of competency; however, they are likely to make up a smaller percentage of training time. The focus at the intermediate stage should shift to maximum strength development, owing to reported high correlations (r = 0.95) existing between maximum strength and weightlifting performance (72).

In instances where the athlete started their development during childhood, they are likely to be in the postpubertal stage of maturation. The postpubertal stage of maturation is associated with altered sex hormone concentrations, leading to natural increases in muscle mass and force-producing capabilities (49,109). In accordance with the focus of strength development, it is suggested that to further develop athletic potential in adolescents, greater external loads (e.g., $\geq$ 80% of 1RM) should be introduced to provide a progressively overloading stimulus and take advantage of the naturally occurring physiological adaptations. In addition, adolescents may be experiencing improved proprioceptive senses at this stage (87), allowing them to better adapt to the increased complexity of the full movements.

In the interest of continuing the progression in competition exposure, the athlete may look to gain weightlifting competition experience at this stage. Given that the athlete is still refining their performance of the weightlifting movements, the goal at this stage may be to achieve 3 valid attempts for both the clean and jerk and snatch, rather than aiming to achieve the highest weight for each lift. To increase athlete enjoyment and training adherence, this may also provide a good opportunity for the athlete to set some performance goals, with the assistance of the coach, one of which may include achieving 3 valid attempts for both the clean and jerk and snatch. Such an approach prioritizes performance consistency under competition constraints, rather than load lifted and thus competition placing.

ADVANCED

This stage is representative of the autonomous stage of motor learning, whereby the weightlifting movements should require little cognitive involvement from the athlete. The athlete is becoming adept at exploiting forces from the weightlifting movements to ensure flexible and efficient movements (102). Technique errors are likely to be more consistent, not to be mistaken with high movement variability that is present during the early stages of motor learning (7,8). Technical errors presented in training are likely to be only at the heaviest loads and are less likely to be a result of limitations in skill mastery, but rather limitations in force expression and absorption.

At this stage, the athlete should be competent at performing the exercises on all tiers of the progression pyramid, inclusive of full lifts (Figure 2). The coach may select exercise derivatives, rather than just performing the full lifts, to specifically target errors to improve technical performance. Hence, the progression pyramid (Figure 2) should be viewed in such a way that the athlete is not restricted to only exercises listed for their current stage and may perform exercises in the tiers below to target specific technical errors or address physical deficiencies. During the snatch for example, skilled lifters demonstrate a decreased barbell height in comparison to lesser skilled lifters (58), suggesting the importance of speed when dropping under the barbell into the catch position. Therefore, the snatch balance movement may be used to increase athletes' speed under the bar and thus minimize the distance from peak bar displacement to the catch position. Examples of correction exercises to target specific technical errors are presented in Table 2. However, it should be noted that limitations of performance and even poor technique may also reflect physical deficiencies (e.g., strength and power, neuromuscular control) (97). For those athletes where improvement of limiting physical capacities is a necessary focus, weightlifting derivatives can also be prescribed to elicit specific physical adaptations. For example, jump shrugs or pulls could be used to improve explosive strength, owing to their reported high force and power output (27,121,122).

Owing to the shift in training focus, explosive strength development should be a key training priority at this

Table 2 Exercise selection dependent on technical error correction and/or physical adaptation		
Exercise	**Technical error correction**	**Physical adaptation**
Front and overhead squat	Develops catch position stability	Lower-limb strength development
Snatch balance	Develops catch position speed and stability	Lower-limb eccentric strength development
Jump shrug/clean/snatch pulls	Encourages the athlete to achieve hip, knee (and ankle) extension position in second pull phase	High power expression and output during second pull
High hang clean/snatch	Encourages the athlete to achieve hip, knee (and ankle) extension position in second pull phase	High power expression and output, isolating the second pull phase and concentric force production
Hang clean/snatch	Reinforces the correct positioning for end of first pull/start of transition, encouraging the athlete to keep bar path inside the base of support at this position Encourages athlete to achieve hip, knee (and ankle) extension position in second pull phase, after a transition movement	High power expression and output during second pull
Isometric first pull (snatch and clean grip)	Encourages set up positional awareness and helps to ensure correct hip and knee extension during the first pull	Lower-limb strength development in first pull position
First pull (snatch and clean grip)	Encourages set up and first pull positional awareness in isolation	Lower-limb strength development at end ranges
Power clean/snatch	Encourages the athlete to achieve hip, knee (and ankle) extension position in second pull phase	High power expression and output during second pull

stage, especially because the rapid force expression during the second pull of the weightlifting movements has been identified as a key determinant of weightlifting performance (63). The athlete may also look to further increase their weightlifting competition experience at this stage. With refined performance of the weightlifting movements, athletes are at an appropriate stage of their development to progress in load lifted, hence scoring determined by the sum of the highest completed lift in the snatch and clean and jerk is more appropriate.

MANIPULATING VOLUME, INTENSITY, VELOCITY, AND FREQUENCY OF TRAINING

To achieve the desired adaptation, training prescription needs to be specific to challenge the aspects of motor learning and strength development. For example, if the desired adaptation is to increase maximal strength in advanced athletes, training needs to include loads that recruit high threshold motor units (≥80% of 1RM), low volumes (<5 reps) and longer rest intervals between sets (≥3 minutes) to allow for full phosphocreatine recovery (48,81). Consequently, the desired training adaptation should be a primary factor in dictating training prescription variables (i.e., volume, intensity, repetition velocity, and training frequency).

VOLUME AND INTENSITY

During the beginner stage, when training is predominantly incorporating AMSC, volumes will typically be higher than those prescribed during the later stages of development that focus on maximal efforts, to provide more opportunities to improve motor learning. Given the unstructured nature of many of the introductory AMSC games and isometric holds, strict sets and repetitions may not initially be prescribed, instead blocks of time (e.g., "seconds of work" might constitute a given set). As the athlete progresses to more structured exercises, a high volume of movement repetitions such as 2–4 sets of 8–12 repetitions should aid in the development of movement competency, providing sufficient exposure to develop motor control, while still allowing for a range of different exercises and movement stimuli to be completed within the same session (86). These higher volumes might also be further broken down into clusters to allow for regular feedback opportunities and avoid error recurrence across a number of repetitions (e.g., set of 12 repetitions divided into 3 clusters of 4 reps). Intensity at this point will be low, with the athlete typically performing bodyweight exercises, and in some cases, exercises might be differentiated by using assistance (e.g., from bands) or changing body position (e.g., incline) to ensure all athletes can perform movements with correct technique.

As the weightlifting movements are introduced at the novice stage, volumes will likely decrease, with sets of ∼3–5 repetitions recommended as being effective during the learning of weightlifting movements (44). For young athletes, competition-based games may still be incorporated into training drills with no load to enhance enjoyment and effort, for example, racing a partner to drop into a front squat catch position. The athlete should first be able to demonstrate technical proficiency with a light resistance such as a wooden dowel or PVC piping, then progress to light barbells (5–10 kg) then to appropriate weightlifting bars (males 20 kg and females 15 kg). Competitive games and challenges can be played when the athletes are performing the movements with no external load, adding a fun element to training; for example, marbles can be sealed inside the PVC pipes so the young athletes can make a noise with them (93) and athletes can race to drop into a catch position on command. It should be emphasized that at no point in the developmental journey should intensity be increased at the expense of movement competency (86). During the circumpubertal stage of maturation, the coach should be mindful of naturally occurring increased movement variability resulting from adolescent awkwardness; rather than adding load to inconsistent and possibly injurious movement, higher repetition volumes may be important to provide sufficient exposure to relearn the movement patterns due to a reduced kinesthetic awareness.

As the athlete's proficiency and technical competency in performing the weightlifting movements continues to develop, the prescribed exercise intensity should increase. At the point in which the athlete is able to demonstrate the full lifts with correct technique across repetitions, it may be appropriate to determine a 1RM, which can then be used to more accurately prescribe the exercise intensity. Despite concerns regarding the safety and reliability of 1RM testing in youth populations in a weightlifting movement, 1 RM power clean testing has been shown to have a high degree of reproducibility in trained adolescent athletes when standardized testing procedures are followed and qualified instruction is present (43). The use of this testing would not be suitable in inexperienced lifters, given that the testing should be technique-driven, with testing aborted once movement deviates from the correct exercise technique. For inexperienced lifters, the use of an isometric midthigh pull assessment may be a safe and reliable alternative to determine the athletes' force-producing capabilities (94). Once the athlete has achieved technical mastery, heavier loads (≥80% of 1RM) can be used to improve strength (31,81). With advanced lifters, supramaximal loads may also be used when the movement is broken down into key phases, such as 120% of clean 1RM for pull to the knee. However, exercises with different intensities should still be used, with the Union of Soviet Socialist Republics National Olympic team reportedly performing only 42% of their total lifting volume above 80% of 1RM during a preparatory training year (130). During postpuberty, this increase in intensity aligns with current recommendations, which suggest that at this stage of maturation, athletic potential is best developed through increases in external load (87), often accompanied by a reduction in training volume (106).

As the training focus shifts to the development of explosive strength, the coach must ensure sufficient rest between sets (typically ≥ 2 minutes), allowing for recovery to ensure the intensity and/or speed of movement can remain high in subsequent sets. In accordance with these recommendations, research advocates the use of high intensity (80–89% of 1RM) and longer durations of rest (3–4 minutes) for greater strength gains in experienced young athletes (81). For a competing athlete, a coach should be mindful of the need to develop recovery ability for competition due to the maximum rest of only 2 minutes between lift attempts. A coach may therefore reduce this rest where possible, while ensuring technique is not compromised as a result.

REPETITION VELOCITY

Movement precision is likely to decrease as a result of increased movement speed, in agreement with Fitts's law (46). Therefore, when athletes are first learning the AMSC, they should be encouraged to perform the movements in a controlled manner to ensure they achieve the correct positions throughout. The stability of motor performance in youth can be greater in tasks that require maximum effort in comparison to those that demand accuracy (13). Therefore, coaches should be cognizant of potentially higher movement variability when performing controlled movements (e.g., dowel hinge) in comparison to rapid, explosive movements (e.g., takeoff mechanics in a countermovement jump).

Rate of force development is a key determinant of weightlifting performance (120); therefore, ensuring that weightlifting movements involve explosiveness should aid training adaptations and overall performance. Likewise, negative transfer from learning the movements under a speed constraint may occur if the movements are instead performed in a slow and controlled manner (114). Therefore, when the athlete begins to perform the weightlifting movements and the associated derivatives, they should be instructed to perform the exercise at maximal velocity. When athletes are learning the weightlifting movements and the associated derivatives, the use of a pause at key positions may be advantageous to ensure they achieve the correct positions at the end of each phase, and master proper technique, while still allowing for performance at maximal velocity. This may also help the athlete to develop strength in these positions. Examples include pausing at the end of the first pull to ensure the position is correct, before performing an explosive hang clean or snatch, and pausing in the receiving position of a clean to ensure the athlete is balanced and the base of support remains stable, before standing up in the recovery phase. Research indicates that when maximal intended velocity is applied during an exercise, significantly greater increases in strength and power are observed over training performed with equal loads but lower velocities (10). It seems that it is the intent to move fast that is of key importance, with beneficial adaptations occurring even if the athlete is unable to physically increase the velocity of the movement. These high contraction velocities may also maximize the transfer to specific sports skills (129).

Given the inverse relationship between load and movement velocity, the coach may consider manipulating the load to maximize power and velocity. Research suggests that training at the load that maximizes power output may lead to superior increases in power output as compared to other training means (127). Velocity-based training, which is becoming more readily available to coaches through mobile phone applications, may therefore be an advantageous tool for coaches when prescribing training load. As well as being beneficial for monitoring purposes and accurate estimations of exercise 1RM (5), this tool may also enhance buy-in and stimulate interest in younger populations, providing regular within-session feedback.

FREQUENCY

Research suggests adaptations can be made in athletes naive to weightlifting from only 2 one-hour sessions a week (64). However, research has not established the most effective dose-response relationship for learning weightlifting; therefore, current guidelines on training frequency are based on inferences from resistance training interventions. During the initial stages of learning, it has been suggested that training should not exceed 3 hours a week, especially with young athletes (86). These hours could be made up of three 1-hour sessions, or more frequent but shorter 30–40-minute sessions. Such training frequency provides a micro-dosed effect, which is arguably more beneficial for the development of skill retention allowing for more latent, between-session and posttraining learning to emerge (95). Training frequency can then increase as movement competency improves and the athlete progresses through the progression scheme, with upward of 6 sessions a week being suitable for more advanced-level weightlifters.

Table 3
Key performance Indicators for each phase of the weightlifting movements (9,16,18,52,58,63,77,79,129) (base of support = metatarsal-phalangeal joint to ankle, vertical reference line = vertical line drawn through the center of the barbell just before liftoff)

Start position
Bar positioned above metatarsal-phalangeal joint
Athlete's shoulders positioned above or in front of the bar
First pull
Athlete torso angle remains constant
"Controlled" speed of hip and knee extension, moving to a position with shins perpendicular (or close to perpendicular) to the floor
Upward or rearward direction of the bar, ensuring the bar path remains inside the base of support (in the sagittal plane)
Transition
Flexion-extension should occur predominantly at the athlete's knees, with minimal hip joint excursion
Barbell should continue to move upward
Bar path must remain inside base of support (in the sagittal plane)
Second pull
Rapid hip and knee extension and ankle plantar flexion
Bar path must remain inside base of support (in the sagittal plane) with peak bar vertical displacement at the end of the phase achieved at or behind the vertical reference line
Catch position
From a position of maximum barbell height to the catch position, bar vertical displacement should be minimized; however, there should be greater vertical displacement of the bar in comparison to horizontal (not forward)
The bar position in the catch must be behind the start position or behind the vertical reference line
Base of support (in the sagittal plane) may remain on the spot or travel backward no greater than ½ its width

A higher training frequency, balanced against appropriate rest times, may be required to maintain the minimum effective dose as athlete training experience increases. The athlete needs sufficient recovery to ensure they can perform subsequent sessions at the desired training volumes and intensity, and to allow time for central nervous system recovery and adaptations to manifest from training-induced physiological stress. Without

Table 4
Task constraints for common errors in the performance of weightlifting tasks

Error	Task constraint	Image
Barbell moves away from the athlete, outside the athlete's base of support during the second pull phase of the movement.	Position an object in front of the athlete as an obstruction to any forward bar movement when performing derivatives from the hang position.	
Athlete does not achieve full hip extension during the second pull phase of the movement.	Position a soft object above the athlete, with the athlete aiming to touch their head on the mat.	
Bar moves away from the athlete, outside the athlete's base of support and/or athlete's base of support travels forward in the catch position.	Athlete starts a hang variation of the lifts on the edge of a raised platform or with a marker on the floor. To avoid moving forward, they ensure their base of support remains on the spot or travels backward during the catch phase.	
Barbell is pressed vertically rather than the athlete dropping under the bar during the snatch balance.	Position a dowel above the barbell when it is positioned on the athlete's back as an obstruct and minimize vertical bar movement when catching.	
Athlete is using an undesirable countermovement to initiate the high hang or hang weightlifting variations before hip extension.	Position the barbell on blocks, preventing any downward movement of the bar and joint flexion.	

sufficient recovery, the athlete will show compromises in their weightlifting technique as a result of fatigue. The coach should therefore be mindful that 48 hours is typically the time required for optimal recovery from fatigue induced by typical weightlifting training; hence, any training inside of this period may involve performance under fatigue (25). Monitoring tools can be advantageous for coaches to determine factors important to the recovery process, such as athlete fatigue status, readiness to train, sleep, and nutrition. Monitoring tools may comprise objective monitoring, such as jump performance variables and heart rate, in addition to subjective monitoring such as wellbeing questionnaires (including information such as nutrition, sleep hours and quality, fatigue, soreness, mood, stress, and health) and informal discussions with athletes.

COACHING CONSIDERATION

A CONSTRAINTS-BASED APPROACH FOR WEIGHTLIFTING SKILL DEVELOPMENT

Given the importance of movement technique, the coach must ensure the athlete is performing the exercise progressions with proficient and "correct" movement technique. Given the task constraints in the weightlifting movements and strict rules of the events in competition, it might be assumed that large interindividual variations in the lifting technique would not be present. However, contrary to this intuition, although most lifters use similar technical styles of lifting, there is often high interindividual variability in the barbell trajectories and kinematic or kinetic characteristics of weightlifting movements among highly skilled athletes (3,7,8,14). These findings indicate that copying the movement of successful athletes may be a suboptimal approach for skill acquisition; therefore, teaching techniques designed to promote ideal optimal movement solutions, such as modeling perfect skills, might be redundant (14). Instead of adopting stringent technical models, an alternative approach is to use key performance indicators (Table 3). Notwithstanding the importance of coach instruction and safe technique, adopting a somewhat less rigid instructional approach encourages the athlete to search for their own effective coordination solution (32,102).

Effective task constraints provide the athlete with immediate information on the quality of the movement, termed knowledge of performance, while providing an external focus of attention (115,125). For example, the athlete can gain feedback from contacting an obstruction such as a wooden dowel, if the bar path deviates away from its optimal bar path (Table 4). This knowledge of performance can result in better motor coordination outcomes and overall improved athletic performance (115). A constraints-based approach to coaching also allows individuals to find movement solutions based on unchangeable individual constraints, such as limb length, rather than trying to mold an athlete to conform to a technical model that is not suitable to their constraints. Such an approach is likely to be advantageous with young athletes, who will experience changes in limb lengths resulting from growth and maturation (103). Importantly, the challenge of performing the tasks under different constraints and training variety also has the potential to increase athlete enjoyment, effort, and performance (24). Table 4 provides coaches with a series of task constraints to address common technical errors that may occur during the weightlifting movements. When constructing task constraints, as long as the coach ensures they are in accordance with the key performance indicators, they are only limited by their own imagination, with many existing for coaching the power clean alone for example (125).

INSTRUCTION AND FEEDBACK

Throughout all stages of the progression scheme, athletes should receive relevant feedback on performance to ensure any errors are not repeated across a number of repetitions. When the athlete is unable to find the correct position, hold the correct position, or repeatedly move in and out of the correct position, the coach should first attempt to cue the athlete to correct the error (42). An athlete's ability and stage in the skill acquisition process should affect the cueing and feedback. The level of coach to athlete interaction or amount of feedback may begin high but gradually reduce as the athlete becomes more proficient at the movements, a process known as "scaffolding." However, as a result of the nonlinear nature of development and skill mastery, the coach must be prepared for random fluctuations in performance and thus the need to alter the amount of feedback accordingly (74). Athletes with a higher training age can process cues and instructions more effectively than a novice (26); therefore, it is important that during the early stages of learning the weightlifting movements that the coach does not overload the athlete with instruction and feedback, focusing on a maximum of 1–3 key points at any given point in time. For example, in a squat, the coach may first cue the athlete to drive their heels into the floor and show off their T-shirt logo. For novice athletes, the coach should consider delaying feedback when possible to avoid creating feedback dependency and improve skill retention (123); however, as a caveat, feedback or some form of intervention should be actioned immediately if there is clear performance of an injurious movement (e.g., immediate feedback should be given to the athlete if they are unable to maintain a neutral spine throughout any of the movements, especially loaded movements). Once the athlete has achieved technical competence, the coach should not neglect the importance of cueing the athlete to perform with maximal intent to optimize the performance and elicited adaptations. For example, using the cues such as "drive away from the floor," "punch up toward the ceiling," and "snap under the bar" encourage the athlete to perform with intent to move quickly and optimizes neural adaptations, irrespective of training experience (10).

Equally, the cognitive maturity of an athlete can have an influence on their ability to process and implement coaching cues (75,80,98). A coach therefore needs to be mindful of this and may consider adjusting their cueing and feedback strategy according to the athlete's maturity status. During the prepubertal stage of maturation, children typically possess lower levels of vocabulary and comprehension skills (80). Consequently, rather than cueing the athlete to "extend their hips in the second pull phase," the use of an analogies and metaphors such as "explode upward like a firework," "shoot your guns up (elbows)," and "lean over the cliff" can be advantageous to ensure understanding.

Children are also more likely to think in discrete extremes (e.g., black or white, right or wrong) (80), therefore using demonstrations to show the gross movement errors that the athlete is presenting with can help them to better understand and correct the error. Limited memory capacity and attention span during this stage (98) also suggests that immediate feedback may be superior to delayed feedback. Around the circumpubertal stage of maturation, individuals may start to show an increased ability to self-correct (75). As a result, the coach may be able to start to delay feedback to promote self-correction of errors by individuals, ultimately making the athletes more accountable for their own athletic development. The coach should be mindful that as individuals mature and approach the postpubertal stage, they may become more concerned with self-image (4,98). Throughout the athletes' long-term development, the coach should promote *task-involved* goals, focusing on skill development, effort, and self-improvement, as opposed to *ego-orientated* that embody social comparisons (119). High performance, as well as effort, should be acknowledged by praise from the coach to improve the athlete's perceived competence (4).

In addition to coach instruction and feedback, the use of peer-coaching can also be an effective learning tool, whereby more experienced athletes are encouraged to give instruction and feedback to their less experienced peers. Task constraints for example can be easily implemented in a peer-coaching scenario, with both the coach and athlete gaining knowledge of performance feedback. Research suggests the advantages of peer-coaching in comparison to solo practice include improvements in skill performance, self-efficacy, and accuracy of self-assessment of competence, in both youth (126) and adult (116) populations. Likewise, peer motivation should be encouraged by the coach to develop interpersonal skills such as communication, listening, teamwork, and leadership abilities, as well as creating a fun and enjoyable training environment, optimal for fostering long-term enjoyment in training.

SUMMARY

The approach to the long-term development of weightlifting performance presented within the current article aims to provide coaches with a useful resource for the development of weightlifting abilities for young athletes. Central to the progression scheme is the importance of developing robust weightlifting technique. Training at all stages should consider the simultaneous development of movement skills and physical capacities, and the prescription and exercise selection should be manipulated accordingly. Although technical competency and target adaptations should be the key drivers for exercise prescription for young athletes, to take advantage of naturally occurring physiological adaptations and to appropriately match coaching cues according to cognitive development, the athlete's stage of maturation should also be considered. Finally, the use of task constraints may be beneficial for skill acquisition of the weightlifting movements, allowing athletes to find their own, individual movement solution. Providing the coach ensures these task constraints in accordance with the key weightlifting performance indicators, they are limited only by their own imagination.

Conflicts of Interest and Source of Funding: The authors report no conflicts of interest and no source of funding.

Stephanie J. Morris *is currently reading for a PhD in Youth Weightlifting and is a coach in the Youth Physical Development Centre at Cardiff Metropolitan University.*

Jon L. Oliver *is a professor of Applied Paediatric Exercise Science and cofounder of the Youth Physical Development Centre at Cardiff Metropolitan University.*

Jason S. Pedley *is programme director of the Sports Conditioning, Rehabilitation and Massage degree at Cardiff Metropolitan University and a strength and conditioning coach within the Youth Physical Development Centre at Cardiff Metropolitan University.*

G. Gregory Haff *is the professor of Strength and Conditioning and course coordinator for the Masters of Exercise Science (Strength and Conditioning) at Edith Cowan University.*

Rhodri S. Lloyd *is a reader in Paediatric Strength and Conditioning and chair of the Youth Physical Development Centre at Cardiff Metropolitan University.*

REFERENCES

1. Aasa U, Svartholm I, Andersson F, Berglund L. Injuries among weightlifters and powerlifters: A systematic review. *Br J Sports Med* 51: 211–219, 2017.
2. Abernethy B, Kippers V, Pandy MG, Hanrahan SJ. *Biophysical Foundations of Human Movement*. Champaign, IL: Human Kinetics, 2013.
3. Akkus H. Kinematic analysis of the snatch lift with elite female weightlifters during the 2010 world weightlifting championship. *J Strength Cond Res* 26: 897–905, 2012.
4. Allen J, Howe BL. Player ability, coach feedback, and female adolescent athletes' perceived competence and satisfaction. *J Sport Exerc Psy* 20: 280–299, 1998.
5. Balsalobre-Fernández C, Marchante D, Muñoz-López M, Jiménez S. Validity and reliability of a novel iPhone app for the measurement of barbell velocity and 1RM on the bench-press exercise. *J Sports Sci* 36: 64–70, 2018.
6. Balyi I, Hamilton A. *Long-term Athlete Development: Trainability in Childhood and Adolescence. Windows of opportunity. Optimal Trainability*. Victoria, BC: National Coaching Institute British Columbia & Advanced Training and Performance Ltd, 2004.
7. Bartlett R, Müller E, Lindinger S, Brunner F, Morriss C. Three-dimensional evaluation of the kinematic release parameters for javelin throwers of different skill levels. *J Appl Biomech* 12: 58–71, 1996.
8. Bartlett R, Wheat J, Robins M. Is movement variability important for sports biomechanists? *Sport Biomech* 6: 224–243, 2007.
9. Baumann W, Gross V, Quade K, Galbierz P, Schwirtz A. The snatch technique of world class weightlifters at the 1985 world championships. *J Appl Biomech* 4: 68–89, 1988.
10. Behm DG, Sale DG. Intended rather than actual movement velocity determines velocity-specific training response. *J Appl Physiol* 74: 359–368, 1993.
11. Behringer M, vom Heede A,Matthews M, Mester J. Effects of strength training on motor performance skills in children and adolescents: A meta-analysis. *Pediatr Exerc Sci* 23: 186–206, 2011.
12. Bernstein N. *The Co-ordination and Regulation of Movements*. London, UK: Pergamon Press, 1966.
13. Branta C, Haubenstricker J, Seefeldt V. Age changes in motor skills during childhood and adolescence. *Exerc Sport Sci Rev* 12: 467–520, 1984.
14. Brymer E, Renshaw I. An introduction to the constraints-led approach to learning in outdoor education. *J Environ Educ* 14: 33–41, 2010.
15. Buitrago M, Jianping M. Chinese weightlifting: Technical mastery and training. *Amherst: Ma Strength: LLC*, 2018.
16. Burdett RG. Biomechanics of the snatch technique of highly skilled and skilled weightlifters. *Res Q Exerc Sport* 53: 193–197, 1982.
17. Calhoon G, Fry AC. Injury rates and profiles of elite competitive weightlifters. *J Athl Train* 34: 232–238, 1999.
18. Campos J, Poletaev P, Cuesta A, Pablos C, Carratalá V. Kinematical analysis of the snatch in elite male junior weightlifters of different weight categories. *J Strength Cond Res* 20: 843–850, 2006.
19. Canadian FW. Transition phase, long-term athlete development CWFHC, 2003.
20. Capa RL, Audiffren M, Ragot S. The effects of achievement motivation, task difficulty, and goal difficulty on physiological, behavioral, and subjective effort. *Psychophysiology* 45: 859–868, 2008.
21. Carlock JM, Smith SL, Hartman MJ, et al. The relationship between vertical jump power estimates and weightlifting ability: A field-test approach. *J Strength Conditioning Res* 18: 534–539, 2004.
22. Casey B, Galvan A, Hare TA. Changes in cerebral functional organization during cognitive development. *Curr Opin Neurobiol* 15: 239–244, 2005.
23. Chaabene H, Prieske O, Lesinski M, Sandau I, Granacher U. Short-term seasonal development of anthropometry, body composition, physical fitness, and sport-specific performance in young olympic weightlifters. *Sports* 7: 242–255, 2019.
24. Chelladurai P, Stothart C. Backward chaining: A method of teaching motor skills. *Captier J* 44: 16–19, 1978.
25. Chen JL, Yeh DP, Lee JP, et al. Parasympathetic nervous activity mirrors recovery status in weightlifting performance after training. *J Strength Cond Res* 25: 1546–1552, 2011.
26. Clark R, Harrelson GL. Designing instruction that supports cognitive learning processes. *J Athl Train* 37: 152–159, 2002.
27. Comfort P, Allen M, Graham-Smith P. Comparisons of peak ground reaction force and rate of force development during variations of the power clean. *J Strength Cond Res* 25: 1235–1239, 2011.
28. Comfort P, McMahon JJ, Fletcher C. No kinetic differences during variations of the power clean in inexperienced female collegiate athletes. *J Strength Cond Res* 27: 363–368, 2013.
29. Comfort P, Williams R, Suchomel TJ, Lake JP. A comparison of catch phase force-time characteristics during clean derivatives from the knee. *J Strength Cond Res* 31: 1911–1918, 2017.
30. Cooke A, Kavussanu M, McIntyre D, Ring C. The effects of individual and team competitions on performance, emotions, and effort. *J Sport Exerc Psy* 35: 132–143, 2013.
31. Cormie P, McGuigan MR, Newton RU. Developing maximal neuromuscular power: Part 2-training considerations for improving maximal power production. *Sports Med* 41: 125–146, 2011.
32. Davids K, Arau´jo D, Shuttleworth R. Science and football. In: *Applications of Dynamical Systems Theory to Football.* Reilly T, Cabri J and Araújo D, eds. London: Routledge, 2005. pp. 547–560.
33. Dayan E, Cohen LG. Neuroplasticity subserving motor skill learning. *Neuron* 72: 443–454, 2011.
34. Dobbs IJ, Oliver JL, Wong MA, Moore IS, Myer GD, Lloyd RS. Effects of a 4-week neuromuscular training program on movement competency during the back-squat assessment in pre–and post–peak height velocity male athletes. *J Strength Cond Res*, 2019.
35. Duba J, Gerard MA. A 6-step progression model for teaching the hang power clean. *Strength Cond J* 29: 26–35, 2007.

36. Duba J, Kraemer WJ, Gerard MA. Progressing from the hang power clean to the power clean: A 4-step model. *Strength Cond J* 31: 58–66, 2009.
37. Dusault CA. Backward shaping progression of the volleyball spike approach and jump. *Volleyball Tech J* 8: 33–41, 1986.
38. Ebben WP, Blackard DO. Strength and conditioning practices of national Football League strength and conditioning coaches. *J Strength Cond Res* 15: 48–58, 2001.
39. Ebben WP, Carroll RM, Simenz CJ. Strength and conditioning practices of national Hockey League strength and conditioning coaches. *J Strength Cond Res* 18: 889–897, 2004.
40. Enoka RM. Load- and skill-related changes in segmental contributions to a weightlifting movement. *Med Sci Sports Exerc* 20: 178–187, 1988.
41. Faigenbaum AD, Kraemer WJ, Blimkie CJ, et al. Youth resistance training: Updated position statement paper from the national strength and conditioning association. *J Strength Cond Res* 23: 60–79, 2009.
42. Faigenbaum AD, Lloyd RS, Oliver JL. *Essentials of Youth Fitness*. Champaign, IL: Human Kinetics, 2019.
43. Faigenbaum AD, McFarland JE, Herman RE, et al. Reliability of the one-repetition-maximum power clean test in adolescent athletes. *J Strength Cond Res* 26: 432–437, 2012.
44. Faigenbaum AD, Polakowski C. Olympic-style weightlifting, kid style. *Strength Cond J* 21: 73–76, 1999.
45. Felici F, Rosponi A, Sbriccoli P, Filligoi GC, Fattorini L, Marchetti M. Linear and non-linear analysis of surface electromyograms in weightlifters. *Eur J Appl Physiol* 84: 337–342, 2001.
46. Fitts PM. The information capacity of the human motor system in controlling the amplitude of movement. *J Exp Psychol* 47: 381–391, 1954.
47. Fitts PM, Posner M. *Human Performance*. Oxford, England: Brooks/Cole, 1967.
48. Fleck SJ, Kraemer W. *Designing Resistance Training Programs*. Champaign, IL: Human Kinetics, 2014.
49. Ford P, De Ste Croix MB, Lloyd RS, et al. The long-term athlete development model: Physiological evidence and application. *J Sports Sci* 29: 389–402, 2011.
50. Gaetano R, Paloma FG, Gaetano A. Anxiety in the youth physical and sport activity. *Mediterr J Soc Sci* 6: 227–230, 2015.
51. Garhammer J. Power production by olympic weightlifters. *Med Sci Sports Exerc* 12: 54–60, 1980.
52. Garhammer J. Biomechanical profiles of olympic weightlifters. *J Appl Biomech* 1: 122–130, 1985.
53. Garhammer JA. Comparison of maximal power outputs between elite male and female weightlifters in competition. *J Appl Biomech* 7: 3–11, 1991.
54. Garhammer J. A review of power output studies of olympic and powerlifting: Methodology. *Perform J Strength Cond Res* 7: 76–89, 1993.
55. Garhammer J, McLaughlin T. Power output as a function of load variation in olympic and power lifting. *J Biomech* 13: 198, 1980.
56. Gentry RM. *A Comparison of Two Instructional Methods of Teaching the Power Clean Weight Training Exercise to Intercollegiate Football Players with Novice Power Clean Experience [Thesis]*: Faculty of the Virginia Polytechnic Institute and State University, 1999.
57. Gogtay N, Giedd JN, Lusk L, et al. Dynamic mapping of human cortical development during childhood through early adulthood. *PNAS* 101: 8174–8179, 2004.
58. Gourgoulis V, Aggeloussis N, Garas A, Mavromatis G. Unsuccessful vs. Successful performance in snatch lifts: A kinematic approach. *J Strength Cond Res* 23: 486–494, 2009.
59. Hackett D, Davies T, Soomro N, Halaki M. Olympic weightlifting training improves vertical jump height in sportspeople: A systematic review with meta-analysis. *Br J Sports Med* 50: 865–872, 2016.
60. Haff GG, Haff EE. Weightlifting for young athletes in: Strength and conditioning for young athletes. Lloyd RS and Oliver JL, eds. Oxford, UK: Routledge, 2020, pp. 155–187.
61. Häkkinen K, Komi PV, Kauhanen H. Electromyographic and force production characteristics of leg extensor muscles of elite weight lifters during isometric, concentric, and various stretch-shortening cycle exercises. *Int J Sports Med* 7: 144–151, 1986.
62. Handford CH. Serving up variability and stability. In: *Movement System Variability*. Davids K, Bennett S and Newell KM, eds. Champaign, IL: Human Kinetics, 2006. pp. 73–84.
63. Harbili EA. Gender-based kinematic, kinetic analysis of the snatch lift in elite weightlifters in 69-kg category. *J Sports Sci Med* 11: 162–169, 2012.
64. Haug WB, Drinkwater EJ, Chapman DW. Learning the hang power clean: Kinetic, kinematic, and technical changes in four weightlifting naive athletes. *J Strength Cond Res* 29: 1766–1779, 2015.
65. Hedrick A. Teaching the clean. *Strength Cond J* 26: 70–72, 2004.
66. Hirtz P, Starosta W. Sensitive and critical periods of motor co-ordination development and its relation to motor learning. *J Hum Kinet* 7: 19–28, 2002.
67. Hoffman JR, Cooper J, Wendell M, Kang J. Comparison of olympic vs. Traditional power lifting training programs in Football players. *J Strength Cond Res* 18: 129–135, 2004.
68. Hori N, Newton RU, Nosaka K, Stone MH. Weightlifting exercises enhance athletic performance that requires high-load speed strength. *Strength Cond J* 24: 50–55, 2005.
69. Hydock DS. The weightlifting pull in power development. *Strength Cond J* 23: 32–37, 2001.
70. Izquierdo M, Häkkinen K, Gonzalez-Badillo JJ, Ibanez J, Gorostiaga EM. Effects of long-term training specificity on maximal strength and power of the upper and lower extremities in athletes from different sports. *Eur J Appl Physiol* 87: 264–271, 2002.
71. James LP, Comfort P, Suchomel TJ, Kelly VG, Beckman EM, Haff G. Influence of power clean ability and training age on adaptations to weightlifting-style training. *J Strength Cond Res* 33: 2936–2944, 2019.
72. Joffe F. Neuromuscular predictors of competition performance in advanced international female weightlifters: A cross sectional and longitudinal analysis. *J Sports Sci*: 1–9, 2020 [e-pub ehad of print].
73. Johnson JH. Overuse injuries in young athletes: Cause and prevention. *Strength Cond J* 30: 27–31, 2008.
74. Jones RL, Thomas GL. Coaching as “scaffolded” practice: Further insights into sport pedagogy. *Sports Coach Rev* 4: 65–79, 2015.
75. Kesek A, Zelazo PD, Lewis MD. The development of executive cognitive function and emotion regulation in

adolescence. In: *Adolescent Amotional Development and the Emergence of Depressive Disorders*. A N and S L, eds. Cambridge, England: Cambridge University Press, 2008. pp. 135–155.

76. Khan K, Brown J, Way S, et al. Overuse injuries in classical ballet. *Sports Med* 19: 341–357, 1995.

77. Kipp K, Redden J, Sabick MB, Harris C. Weightlifting performance is related to kinematic and kinetic patterns of the hip and knee joints. *J Strength Cond Res* 26: 1838–1844, 2012.

78. Kite R, Lloyd RS, Hamill B. British weight lifting position statement. *Youth Weightlifting Br Weight Lifting*: 1–9, 2016.

79. Korkmaz S, Harbili E. Biomechanical analysis of the snatch technique in junior elite female weightlifters. *J Sports Sci* 34: 1088–1093, 2016.

80. Kushner AM, Kiefer AW, Lesnick S, Faigenbaum AD, Kashikar-Zuck S, Myer GD. Training the developing brain Part II: Cognitive considerations for youth instruction and feedback. *Curr Sports Med Rep* 14: 235–243, 2015.

81. Lesinski M, Prieske O, Granacher U. Effects and dose–response relationships of resistance training on physical performance in youth athletes: A systematic review and meta-analysis. *Br J Sports Med* 50: 781–795, 2016.

82. Lloyd RS, Cronin JB, Faigenbaum AD, et al. National strength and conditioning association position statement on long-term athletic development. *J Strength Cond Res* 30: 1491–1509, 2016.

83. Lloyd RS, Faigenbaum AD, Stone MH, et al. Position statement on youth resistance training: The 2014 international consensus. *Br J Sports Med* 48: 498–505, 2014.

84. Lloyd RS, Meyers RW, Oliver J. The natural development and trainability of plyometric ability during childhood. *Strength Cond J* 33: 23–32, 2011.

85. Lloyd RS, Moeskops S, Granacher U. RS LLoyd and Oliver JO, eds. *Motor Skill Training for Young Athletes in: Strength and Conditioning for Young Athletes*. Oxford, UK: Routledge, 2020. pp. 103–130.

86. Lloyd RS, Oliver J, Meyers R, Moody JA, Stone MH. Long-term athletic development and its application to youth weightlifting. *Strength Cond J* 34: 55–66, 2012.

87. Lloyd RS, Oliver JL. The youth physical development model: A new approach to long-term athletic development. *Strength Cond J* 34: 61–72, 2012.

88. Lloyd RS, Oliver JL, Faigenbaum AD, et al. Long-term athletic development, Part 2: Barriers to success and potential solutions. *J Strength Cond Res* 29: 1451–1464, 2015.

89. MacKenzie SJ, Lavers RJ, Wallace BB. A biomechanical comparison of the vertical jump, power clean, and jump squat. *J Sports Sci* 32: 1576–1585, 2014.

90. Magill RA, Anderson D. *Motor Learning and Control: Concepts and Applications*. NY: McGraw-Hill Publishing, 2007.

91. Malina RM, Rogol AD, Cumming SP, Silva MJC, Figueiredo AJ. Biological maturation of youth athletes: Assessment and implications. *Br J Sports Med* 49: 852–859, 2015.

92. Maschette W. Correcting technique problems of a successful junior athlete. *Sport Coach* 9: 14–17, 1985.

93. Mediate P, Faigenbaun A. *Medicine Ball for All Training Handbook*. Monterey, CA: Healthy Leaning, 2004.

94. Moeskops S, Oliver JL, Read PJ, et al. Within-and between-session reliability of the isometric mid-thigh pull in young female athletes. *J Strength Cond Res* 32: 1892–1901, 2018.

95. Molloy K, Moore DR, Sohoglu E, Amitay S. Less is more: Latent learning is maximized by shorter training sessions in auditory perceptual learning. *PLoS One*, 2012.

96. Myer GD, Faigenbaum AD, Edwards NM, Clark JF, Best TM, Sallis RE. Sixty minutes of what? A developing brain perspective for activating children with an integrative exercise approach. *Br J Sports Med* 49: 1510–1516, 2015.

97. Myer GD, Kushner AM, Brent JL, et al. The back squat: A proposed assessment of functional deficits and technical factors that limit performance. *Strength Cond J* 36: 4, 2014.

98. Myer GD, Kushner AM, Faigenbaum AD, Kiefer A, Kashikar-Zuck S, Clark JF. Training the developing brain, part I: Cognitive developmental considerations for training youth. *Curr Sports Med Rep* 12: 304–310, 2013.

99. Myer GD, Lloyd RS, Brent JL, Faigenbaum AD. How young is "too young" to start training? *ACSMS Health Fit J* 17: 14, 2013.

100. Myer GD, Quatman CE, Khoury J, Wall EJ, Hewett TE. Youth versus adult "weightlifting" injuries presenting to United States emergency rooms: Accidental versus nonaccidental injury mechanisms. *J Strength Cond Res* 23: 2054–2060, 2009.

101. Nagao H, Kubo Y, Tsuno T, Kurosaka S, Muto MA. Biomechanical comparison of successful and unsuccessful snatch attempts among elite male weightlifters. *Sports* 7: 151–160, 2019.

102. Newell KM. Coordination, control and skill. In: Goodman D, Franks IM and Wilberg RB, eds. *Differing Perspectives in Motor Learning, Memory, and Control*. Amsterdam, North Holland: Elsevier Science, 1985.

103. Oliver JL, Barillas SR, Lloyd RS, Moore I, Pedley J. External cueing influences drop jump performance in trained young soccer players. *J Strength Cond Res*, 2019.

104. Oranchuk DJ, Robinson TL, Switaj ZJ, Drinkwater EJ. Comparison of the hang high pull and loaded jump squat for the development of vertical jump and isometric force-time characteristics. *J Strength Cond Res* 33: 17–24, 2019.

105. Pichardo AW, Oliver JL, Harrison CB, Maulder PS, Lloyd RS, Kandoi R. Effects of combined resistance training and weightlifting on injury risk factors and resistance training skill of adolescent males. *J Strength Cond Res*, 2019.

106. Pistilli EE, Kaminsky DE, Totten L, Miller D. An 8-week periodized mesocycle leading to a national level weightlifting competition. *Strength Cond J* 26: 62–68, 2004.

107. Potts N. *An Investigation into the Influence of Learning Strategy on the Acqusition of the Clean. PhD Thesis*. Edinburgh: University of Edinburgh, 2009.

108. Radnor JM, Moeskops S, Morris SJ, et al. Developing athletic motor skill competencies in youth. *Strength Cond J*, 2020, In press.

109. Radnor JM, Oliver JL, Waugh CM, Myer GD, Lloyd RS. The influence of maturity status on muscle architecture in school-aged boys. *Pediatr Exerc Sci* 31: 89–96, 2020.

110. Renshaw I, Chow JY, Davids K, Button C. *Nonlinear Pedagogy in Skill Acquisition: An Introduction*. London: Routledge, 2015.

111. Renshaw I, Chow JY, Davids K, Hammond JA. Constraints-led perspective to understanding skill acquisition and game play: A basis for integration of motor learning theory and

physical education praxis? *Phys Educ Sport Pedagogy* 15: 117–137, 2010.

112. Renshaw I, Davids K, Savelsbergh G. *Motor Learning in Practice: A Constraints-Led Approach*. London: Routledge, 2010.
113. Sandercock GRH, Cohen DD. Temporal trends in muscular fitness of English 10-year-Olds 1998–2014: An allometric approach. *J Sci Med Sport* 22: 201–205, 2019.
114. Schmidt RA, Lee TD, Winstein C, Wulf G, Zelaznik HN. *Motor Control and Learning: A Behavioral Emphasis*. Champaign, IL: Human Kinetics, 2018.
115. Sharma DA, Chevidikunnan MF, Khan FR, Gaowgzeh RA. Effectiveness of knowledge of result and knowledge of performance in the learning of a skilled motor activity by healthy young adults. *J Phys Ther* 28: 1482–1486, 2016.
116. Shea CH, Wulf G, Whltacre C. Enhancing training efficiency and effectiveness through the use of dyad training. *J Mot Behav* 31: 119–125, 1999.
117. Sherman CA, Rushall B. Improving swimming stroke using reverse teaching: A case study. *Appl Res Coaching Athletics Annu*: 123–143, 1993.
118. Simenz CJ, Dugan CA, Ebben WP. Strength and conditioning practices of national Basketball association strength and conditioning coaches. *J Strength Cond Res* 19: 495–504, 2005.
119. Smith RE, Smoll FL, Cumming SP. Motivational climate and changes in young athletes' achievement goal orientations. *Motiv Emot* 33: 173–183, 2009.
120. Suchomel TJ, Beckham GK, Wright GA. Effect of various loads on the force-time characteristics of the hang high pull. *J Strength Conditioning Res* 29: 1295–1301, 2015.
121. Suchomel TJ, Comfort P, Stone MH. Weightlifting pulling derivatives: Rationale for implementation and application. *Sports Med* 45: 823–839, 2015.
122. Suchomel TJ, Sole CJ. Power-time curve comparison between weightlifting derivatives. *J Sports Sci Med* 16: 407–413, 2017.
123. Swinnen SP, Schmidt RA, Nicholson DE, Shapiro DC. Information feedback for skill acquisition: Instantaneous knowledge of results degrades learning. *J Exp Psychol Learn* 16: 706–716, 1990.
124. Vereijken B, Emmerik R, Whiting H, Newell KM. Free (z) ing degrees of freedom in skill acquisition. *J Mot Behav* 24: 133–142, 1992.
125. Verhoeff WJ, Millar SK, Oldham A, Cronin J. Coaching the power clean: A constraints-led approach. *Strength Cond J* 42: 16–25, 2020.
126. Weiss MR, McCullagh P, Smith AL, Berlant AR. Observational learning and the fearful child: Influence of peer models on swimming skill performance and psychological responses. *Res Q Exerc Sport* 69: 380–394, 1998.
127. Wilson G, Newton RU, Murphy AJ, Humphries BJ. The optimal training load for the development of dynamic athletic performance. *Med Sci Sports Exerc* 25: 1279–1286, 1993.
128. Winchester JB, Erickson TM, Blaak JB, McBride JM. Changes in bar-path kinematics and kinetics after power-clean training. *J Strength Cond Res* 19: 177–183, 2005.
129. Young WB. Transfer of strength and power training to sports performance. *Int J Sport Physiol* 1: 74–83, 2006.
130. Zatsiorsky VM. Intensity of strength training: Facts and theory Russian and eastern European approach. *Natl Strength Conditioning Assoc J* 14: 40, 1992.