MANUSCRIPT TITLE:

TAKING A LONG-TERM APPROACH TO THE DEVELOPMENT OF WEIGHTLIFTING ABILITY IN YOUNG ATHLETES

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LONG-TERM DEVELOPMENT OF WEIGHTLIFTING

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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.

KEY WORDS: snatch, clean and jerk, motor learning, resistance training, novice.

INTRODUCTION

Weightlifting is a sport where the snatch and the clean and jerk are contested. In weightlifting competitions, athletes have three attempts to lift the maximum amount of weight in both lifts; with athletes placing within their respective body weight 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/125kg) during the second pull of the clean (55). Power outputs for athletes of similar bodyweights have been found to be two to three times higher in the weightlifting movements than in squats and deadlifts (56). 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 amongst national level male and female lifters (21). Such findings highlight the importance of maximal force and rate of force development for weightlifting performance.

The Transference of Weightlifting

While 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 (52, 54, 69). Considering the high strength and power expression during the competitive weightlifting movements (52, 54, 71), weightlifting training methods are commonly used to develop and improve physical qualities required in many sports (60, 65, 68, 72). Such benefits are especially transferable to explosive movements such as sprinting and jumping (21). Furthermore, performance of 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 (53, 69). 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 (NBA) (119), 88% of National Football League (NFL) (38) and 100% of National Hockey League (NHL) (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 co-ordination of activation of muscle groups and motor units (46, 62). 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 appear especially important, given the declining levels of muscular strength and overall habitual physical activity in young individuals (114).

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. While general models of LTAD exist (6, 50, 88) together with sport-specific (15, 19, 87) 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 (84, 92). 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 (84). The period of childhood appears to be the optimal time to develop coordination and movement competency, as neuromuscular adaptation is heightened due to greater levels of neural plasticity in the developing brain (22). Based upon previous meta-analytical data pre- 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 following 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 (84), following short-term weightlifting interventions (23, 65, 106). 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 (106). 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 (106). Childhood may be the best time to introduce young athletes to weightlifting based training as 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, 58, 97).

While weightlifting exercises and their derivatives have shown to positively influence a number of key performance variables (60, 65, 68, 72), 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 (66). Contrastingly, technique improvements from a short-term weightlifting intervention have been found in athletes naïve to weightlifting, after performing two training sessions per week for four-weeks (65, 72). 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 (105). 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). While the context of each athletic development program is unique to the environment and personnel within that environment, a common goal of long-term athletic development 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 weightlifing 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 (100), 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 (93). 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 (129). Additionally, 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, 53, 90, 102). Poor technique therefore has the potential to impair force production and subsequent improvements in motor control, co-ordination, muscle activation and motor unit recruitment (46, 62).

Correct technique could also reduce injury risk, with poor technique often referenced as an extrinsic risk factor associated with injury (74, 77). 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, 101), 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 (61, 87, 101). 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 (83, 84, 89).

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 long-term athletic development may help coaches to periodize training in a more sequential and progressive manor in order to facilitate the development of optimal technique and overall wellness as well as reducing injury risk (74). Therefore, the purpose of this paper is to present an LTAD model for the development of weightlifting ability. The progression scheme in this paper 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

In order to develop weightlifting technical competency, phases of each lift need to be identified to make learning these complex, multi-joint 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 (61). 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.

Insert table 1 near here

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 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 that 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 (109)), but has had no previous weightlifting exposure should prioritize weightlifting technical development alongside training to improve maximal strength. While the present review offers only an approach to the long term development of weightlifting abilities, the importance of a holistic approach to long-term athletic development 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 (88). Likewise, while this review focuses primarily on the importance of physical development, the emotional and psychosocial aspects of LTAD should not be overlooked.

Insert figure 1 near here

Moving from the outer to inner circles, the four 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 inwards. 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 whilst synonymously improving motor control and body weight management.

The pre-pubertal stage of maturation is typically indicative of higher neural plasticity (88), suggesting a heightened sensitivity to motor control and coordination training. Therefore, athletes should ideally be introduced to weightlifting development during childhood. While 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 (*see 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 inwards 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 long-term athletic development, 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 inwards 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 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, 87). In this approach, the distinct phases in the clean and snatch (*see 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. Additionally, 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, 118). 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 upwards. 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 upwards from AMSC, to foundation strength exercises which serve as foundations for the increasingly more specific weightlifting movements, to then weightlifting derivatives level 1, weightlifting derivatives level 2 and Full lifts.

Insert figure 2 near here

TRAINING FOCUS

Beginner

As a pre-requisite 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 (100). Prior to 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, pre-requisite movements. The focus in the beginner stage should therefore be the development of AMSC (88, 89) the foundation level of the progression pyramid (*see 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, and jumping and rebounding movements are identified categories of AMSC (89). 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 pre-requisites 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 (85). 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, that will be mimicked in the catch position of the snatch and clean and jerk, should first be learnt 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 (85). From here, the athlete has learnt the rudimentary skills to progress onto more weightlifting specific movements learnt 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. Prior to 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; while 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 (109). Before teaching the body weight 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 take-off and landing mechanics (86). 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 (120). 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 (51). The pre-pubertal stage of maturation is typically indicative of lower strength and power expressions but higher mobility and neural plasticity (88). Ideally, children should therefore enter a long-term athletic development program at this stage of maturation in order 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 (42, 84), 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 non-technical 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 pre-requisite 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 (48), 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 (48).

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 in order to achieve the same goal (12). Expending on this concept, Newell's dynamic systems theory proposes that movement is produced from the interaction of multiple sub-systems 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 (103). Dynamic systems theory, suggests that during this early stage of learning, the athlete is creating a coordinative structure; the sub-systems come together and interact in a specific way in order to produce the most efficient, task-specific, movement solution, that would not be not obtainable by any of the sub-systems alone. The appropriate relative motions among relevant muscles, joints and limb segments are assembled to satisfy the task constraints (103).

As such, the use of weightlifting derivatives or movement '*chunking*', rather than the full lifts that demand whole body co-ordination, 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 (*see 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 in order 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 (61). 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 (5-10kg) and then to an appropriate weightlifting bar (males 20kg and females 15kg, respectively).

Given the high-power outputs and key contribution of the second pull phase in the weightlifting movements (21, 27, 52, 70, 122), but low movement complexity, teaching the 'pulling' element of the movement skill, concurrent to the more challenging catch positions may be advantageous (91). Introducing the clean and snatch from a mid 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 (66). 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, whilst teaching a low complexity weightlifting movement (27, 122, 123). While the jump shrug is a good developmental exercise it should be used with caution as it has the potential to result in an over exaggerated 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 whilst 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 athlete 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, 125). 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 (63). The coach should ensure the weightlifting movements are not deconstructed too excessively; therefore, while *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 of 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 (*see 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 (112), or whether learning the new movement may teach performance of abstract movements only partially relevant to the key phases in the full lift (63). 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 circum-pubertal stage of maturation when they reach the novice stage of the progression scheme. The circum-pubertal 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 (87). Research has found 76% of girls and 90% of boys who experience this growth spurt show a clear impairment of coordination (67). 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 (67). 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 circum-pubertal growth spurt may also be accompanied by a reduction in mobility (87). 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 two as separate entities. Such an approach also helps to ensure the pre-requisite movements for more complex movement tasks are achieved in an efficient training order and a delayed training adaptation in weaker, inexperienced athletes is prevented (65). 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 body weight to movements with external load should be used. For example, to develop bilateral strength development, initial prescription could involve a body weight 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 muscles 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 (79). 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 (103). The training focus at this stage is therefore technical autonomy, which aims to promote an enhanced ability to manipulate movement strategies in order to achieve the desired performance outcome and increase the reliability of technical execution in the weightlifting movements.

At this stage, exercises from the weighting derivatives level 1 up to the full lifts on the progression pyramid may be learned (*see 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 not need to be specifically taught providing the appropriate teaching progressions are mastered (57, 108). 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 (*see table 1*). Strength in this motion will have been developed prior to this through the use of RDL's, 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 as 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 (59), 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, in order 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 of 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 is indicative of progression, demanding the athlete to re-organize around a new movement solution (113). Following this increased movement complexity, heightened movement variability may be expected at first, indicative of instability in the movement behavior (111). 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 (73).

In instances where the athlete started their development during childhood, they are likely to be in the post-pubertal stage of maturation. The post-pubertal stage of maturation is associated with altered sex hormone concentrations, leading to natural increases in muscle mass and force producing capabilities (50, 110). In accordance with the focus of strength development, it is suggested that to further develop athletic potential in adolescents, greater external loads (e.g. ≥ 80% of 1RM) should be introduced to provide a progressively overloading stimulus and take advantage of the naturally occurring physiological adaptations. Additionally, adolescents may be experiencing improved proprioceptive senses at this stage (88), 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 three 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 three 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 (103). 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 (*see 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 (59), 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)(98). 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, 122, 123).

Owing to the shift in training focus, explosive strength development should be a key training priority at this stage; especially since the rapid force expression during the second pull of the weightlifting movements has been identified as a key determinant of weightlifting performance (64). 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

In order 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 (49, 82). 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, in order 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 (87). 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 body weight 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 (45). For young athletes, competition-based games may be 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 (5-10kg) then to appropriate weightlifting bars (males 20kg and females 15kg, respectively). 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 (94) 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 (87). During the circum-pubertal 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 (44). 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 mid-thigh pull assessment may be a safe and reliable alternative to determine the athletes force producing capabilities (95). Once the athlete has achieved technical mastery, heavier loads (≥ 80% of 1RM) can be used to improve strength (31, 82). With advanced lifters, supra-maximal 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 (USSR) National Olympic team reportedly performing only 42% of their total lifting volume above 80% of 1RM during a preparatory training year (131). During post puberty, this increase in intensity aligns with current recommendations which suggest that at this stage of maturation athletic potential is best developed via increases in external load (88), often accompanied by a reduction in training volume (107).

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 (82). 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 two minutes between lift attempts. A coach may therefore reduce this rest where possible, while ensuring technique isn't 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 (47). 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. take-off mechanics in a countermovement jump).

Rate-of-force-development is a key determinant of weightlifting performance (121), 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 (115). 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 appears 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 (130).

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 (128). Velocity-based training, which is becoming more readily available to coaches via 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 two, one hour sessions a week (65). 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 three hours a week, especially with young athletes (87). These hours could be made up of three, one-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 post-training learning to emerge (96). Training frequency can then increase as movement competency improves and the athlete progresses through the progression scheme, with upwards of six sessions a week being suitable for more advanced level weightlifters.

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 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 time 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 of 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 inter-individual variations in the lifting technique would not be present. However, contrary to this intuition, while most lifters use similar technical styles of lifting there is often high inter-individual 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 sub-optimal approach for skill acquisition; therefore, teaching techniques designed to promote ideal optimal movement solutions, such as modelling 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 co-ordination solution (32, 103).

Insert table 3 near here

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 (116, 126). 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 (116). 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 (104). 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 the coaching the power clean alone for example (126).

Insert table 4 near here

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 (43). 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 non-linear 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 (75). 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 (124); 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 in order to optimize the performance and elicited adaptations. For example using the cues such as, 'drive away from the floor, 'punch up towards 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 (76, 81, 99). 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 pre-pubertal stage of maturation, children typically possess lower levels of vocabulary and comprehension skills (81). 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 upwards 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) (81), 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 (99) also suggests that immediate feedback may be superior to delayed feedback. Around the circum-pubertal stage of maturation, individuals may start to show an increased ability to self-correct (76). 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 post-pubertal stage, they may become more concerned with self-image (4, 99). 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 (120). 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, accuracy of self-assessment of competence, in both youth (127) and adult (117) 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 manuscript 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. While technical competency and target adaptations should be the key drivers for exercise prescription for young athletes, in order 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.

TABLE TITLES

Table 1. Phases of the clean, jerk and snatch

Table 2. Exercise selection dependent on technical error correction and/or physical adaptations

Table 3. Key performance indicators for each phase of the weightlifting movements (9, 16, 18, 53, 59, 64, 78, 80, 129) (Base of support (BOS) = metatarsal phalangeal joint to ankle, Vertical reference line = vertical line drawn through the center of the barbell just prior to lift-off)

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

FIGURE TITLES

Figure 1. Long-Term Development of Weightlifting Performance Progression Scheme (BW=Body weight)**.** Novice athletes are introduced at the outside circle of the model, and training progresses inwards 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.

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

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