**Introduction**

Weightlifting is a sport consisting of 2 lifts; the snatch (figure 1) and the clean and jerk (C&J) (figure 2 and figure 3, respectively). The athlete has 3 attempts to post at least one successful lift on each discipline, with the snatch preceding the C&J. If an athlete misses all attempts in either discipline they are disqualified from the competition, with the exception of World championships where athletes can medal in the snatch, the C&J and total. The success of a lift is determined by three officials looking for any technical infringements as outlined in the International Weightlifting Federation (IWF) technical and competition rules and regulation (TCRR's) (Ajan, 2017, pp 8-10). Some of the most common infringements which can also be prevalent in novice training include; stopping the upward movements of the bar during the pull, touching the platform with any part of the body other than the feet and finishing overhead with an arm press out.

<FIGURE 1 HERE- SNATCH>

<FIGURE 2 HERE- CLEAN >

<FIGURE 3HERE- JERK >

Competitions are split into male and female groups, with further subdivisions into weight classes (Table 1). The outcome of a competition is defined by the highest weight lifted in the group. Should two individuals achieve the same lift (for individual medals), or same total, the lifter who achieved it first would be the successor. For a more detailed description of the classification process the authors suggest referring to the IWF's TCRR's resource available on the IWF website.

Although not a deciding factor of success the Sinclair total can also be reported at competitions, allowing lifters to see what their total would be if they were in the heaviest weight class. This enables us to fairly compare lighter lifters to the heavier lifters and means the "best lifter" title can be awarded to the person who achieved the highest Sinclair total. To do this the Sinclair equation is utilised (Equation 1) where each bodyweight has an assigned coefficient based on most recent world records (Alberta Weightlifting Association, 2013).

<TABLE 1 HERE - WEIGHTCLASS>.

<INSERT EQUATION 1 HERE>

Technical proficiency in weightlifting can help optimise the lifters chance of success, but given that the aim is to lift the most weight as possible, several performance associated characteristics, such as strength and power also impact the ability to perform (Stone *et al*., 2006). The unique aspect of weightlifting is that a development of technique, strength and power can be developed concurrently. It will therefore be the aim of chapter to provide sound scientific evidence that can help support the development of success in weightlifting.

**Athletic Demands**

The snatch and C&J both require high levels of skill and power (Gourgoulis *et al*., 2000). The kinetics and kinematics of weightlifting have therefore been extensively studied (Kipp and Harris, 2015; Harbili and Alptekin, 2014; Akkus, 2012; Gourgoulis *et al*., 2009; Rossi *et al*., 2007; Bartonietz, 1996), with the most common biomechanical variables measured being barbell and joint kinematics and kinetics. From figures 1 and 2 it is evident that two commonalities exists between the snatch and the clean; bar path and key positions, with subtle differences of bar placement during the power position (figures 1 and 2 c) due to grip width. It is important that the reader understands how the barbell and joints interact with one another as to enable them to appropriately recognise any technical issues or weaknesses in the lifts. Due to the similarities between the two lifts we have looked at the snatch and clean concurrently, with the jerk independently.

*Bar Kinematics and Kinetics*

The shared sequences from the snatch and the clean elicit similar bar trajectories that display a shallow "S" type curve (figure 4). Optimising bar path is a characteristic often considered as prudent in enhancing the chance of success (Stone *et al.*, 1998). Results presented by Stone *et al* (1998) stated that the most successful snatches displayed rearward displacement of the bar from the set to the catch. For both lifts this displacement initially starts from the set-position to the 1st pull (figures 1 and 2, a to b), and continues to do so until the lifter is in the power position (figures 1 and 2 c), and ready to start the 2nd pull. This rearward movement enables the lifter to shift the bars centre of mass closer to their own, thus enabling better transfer of mechanical power from the body to the bar through sequential, intersegmental movements (Funato, Matsuo and Fukunaga, 1996). Once extension of the ankle, knee and hip is achieved during the 2nd pull (figure 1 and 2 d) the bar will display a small loop due to the contact on the hip or mid-thigh, for the snatch and clean respectively. The loop is defined as the horizontal displacement from the bars most forward position during the 2nd pull to the catch (Stone *et al*., 1998). Should the bar loop "excessively" this would adversely affect the lift and increase the likelihood of failure, with the lifter catching too far forward on their feet or jumping forward to realign their centre of mass under the bar. Information pertaining success on the snatch has shown that when the loop exceeded 20 cm there was a 100% failure rate, with the authors suggesting that minimising the loop to approximately 11cm would increase the chance of success (Stone *et al*., 1998). This can be measured through video analysis softwares freely available online, providing a lateral view of the lifter is taken, thus allowing the coach to accurately measure bar path.

<FIGURE 4 HERE – BAR TRAJECTORY>

Optimising bar path will inherently assist in increasing the bars vertical velocity with previous literature reporting that a steady bar velocity between the end of the 1st pull and the start of the 2nd pull, allows for the key positions to be met (Bartonietz, 1996). Although technically undesirable, there is a commonality that velocity of the barbell during the transition phase (between the first pull and power position) slightly decreases, due to the knees moving forward under the bar. Too much of a decrease would mean the lifter is required to overcome the barbells velocity deficit, and to re-accelerate the bar, potentially becoming deleterious to the lift (Bartonietz, 1996; Gourgoulis *et al*., 2000). This therefore means the bar may not travel to the optimum vertical height in order to allow the lifter sufficient time to drop under the bar in preparation for the catch (Hoover *et al*., 2006). Literature attaining information on peak vertical displacement of the bar during the snatch equates to approximately 70% of the lifters height, with lower values (approximately 60%) experienced during the clean (Campos, Cuesta and Pablos, 2006; Haff, *et al*., 2003). This insinuates that a threshold of vertical bar displacement may exist and the ability of the lifter to drop under the bar is of great importance. This is evident in highly skilled weightlifters who achieve a relatively lower barbell height during the catch phase and a faster drop during the turnover (figure 1 and 2 e) (Gourgoulis *et al*., 2002). This suggests that as loads get heavier vertical displacement of the bar will be limited thus requiring the lifter to drop under at a faster rate, as previously reported (Hoover *et al.*, 2006).

< TABLE 2 HERE – BIOMECH TERMINOLOGY>

Understanding mechanical energy, work and power production during the 1st and 2nd pull is of great importance (table 2), as this can help inform programming and has been associated with totals achieved by lifters (Funato, Matsuo and Fukunaga, 1996). The mechanical work output of the 1st pull has been shown to be greater than that of the 2nd pull (Akkus *et al.*, 2012; Gourgoulis *et al*., 2002), but displays relatively lower power outputs (Hoover *et al.*,2006; Gourgoulis *et al*., 2002). This suggests that the 1st pull during both lifts may be a more strength orientated movement and that other physiological mechanisms such as the stretch shortening cycle contribute to the higher power outputs observed in the 2nd pull. Comparatively the snatch and the clean present differing mechanical barbell power outputs, with absolute wattages of 1,847.62 ± 336.06 and up to 3,691 during the 2nd pull of the snatch and clean respectively (Akkus *et al*., 2012; Garhammer, 1991). Variances in both bar trajectories and power output exist between load (Harbilli and Alptekin, 2014 ; Hadi, Akkus, and Harbili, 2012; Comfort, Udall and Jone, 2012), gender (Gourgoulis *et al*., 2002; Garhammer, 1991) and weight class (Isaka, Okada, and Funato, 1996). It is therefore recommended that individual variances are likely to be apparent, and that optimising barbell trajectory based on the aforementioned will require adaptations to body position, in order to meet the key phases, and increase chance of consistency and success. Therefore understanding how the joints interact with one another may help give insight to coaches and lifters alike to be able to adapt coaching methods and programming to each individual lifter as no two lifters are the same.

*Joint kinematics and kinetics*

The movement of the bar is manipulated by the body's ability to leverage itself and get into the most favourable position to develop power, therefore understanding joint kinematics and kinetics can help facilitate the technical and physical training of weightlifters. Primary joints such as the ankle, knee and hip tend to be the most researched joints within weightlifting, based on their ability to harmoniously develop high ground reaction forces, and power outputs (Kipp *et al*., 2012; Gourgoulis *et al*., 2002;Baumann *et al*., 1988; Enoka, 1979). This synchronisation helps the lifter overcome the system mass (sum of barbell mass and body mass) experienced during the lift, as well as optimise barbell trajectory. During the set position, knee, hip and torso angles of 47 and 80°, 34 and 41°, and 118 and 135°, have been reported, respectively, for 2 athletes differing in body dimensions (figure 5) (Lippmann and Klaiber, 1986). The extent at which these angles form the set position will differ between lifters dependent on anthropometric variables and flexibility. Generally speaking, it has been suggested that from a lateral view a lifter should display hips higher than the knees, the torso in an upright position, and the shoulders slightly over the bar (DeWeese *et al*., 2012).

The 1st pull is initiated when the lifter raises the barbell off the ground, back, and towards the knee (Figure 1 and 2 b). This movement is typically controlled in nature taking the longest duration with maximum knee angles reported to be 139 ± 4.19° for male and 129 ± 11° for female elite lifters (Gourgoulis *et al.*, 2002). From a technical stand point extending the knees, keeping the chest up and delaying the rise of the hips help contribute to maintain a constant torso angle relative to the set (DeWeese *et al*., 2012). If hip extension is too rapid in the 1st pull, barbell trajectory will be ineffective (Bartonietz, 1996). To support this, research from Kipp *et al* (2012) found that greater loads were associated ($r$ = 0.766 – 0.870) with a steady trunk position and less hip extension during the 1st pull. Due to the bi-articular function of the hamstrings across the knee and hip, knee extension and reduced hip extension would allow adequate tension in the hamstrings, imperative for maximal power production in the 2nd pull (Everett, 2009, pg 67). As the knees move through the transition phase the lifter is now in a power position (figures 1 and 2 c) and ready to start the 2nd pull. Research measuring clean pulls from the power position present angles at the knee and hip of 141 ± 10° and 124 ± 11° respectively (Kawamori *et al*., 2006), with ground reaction forces displaying the highest force and power outputs relative to the other phases, showing its importance within the lift. It becomes evident that the 1st and 2nd pulls play pivotal roles in enhancing a lifters success, but furthermore lends itself to enhancement through programming for both strength and power.

*The Jerk*

Little literature has been conducted on the jerk alone, but its importance is imperative, as the lifter must jerk what they have cleaned for it to be a successful lift. There are two styles of the jerk; squat and more commonly, the split. Regardless of which one a lifter uses, the dip (figure 3a) and drive (figure 3b) adds an upward momentum to the bar, to allow the athlete enough time to drop under and catch. It is typically conceived that this jerk motion is similar to that of a countermovement jump, however literature from Cleather, Goodwin and Bull (2013) found that joint moments were not significantly correlated to jump height and that the jerk is primarily knee dominant, whereas jumping is more reliant on knee and hip moments. Nevertheless, the high peak powers observed during a jerk (Garhammer, 1980), suggest that there is a utilisation of a stretch reflex, similar to that of a loaded jump. During the catch phase of the jerk (figure 3d) the lifter can experience up to 3.4 ± 1.2 $BW^{\cdot s-1}$ on the lead leg (Lake, Lauder and Dyson, 2006). Upon observation this leg should finish at approximately 113° with the back knee bent at 130° to enable stabilisation. The feet may move out and away from each other slightly, with the front foot slightly turned in to increase the base of support (figure 6).

*Physiology of weightlifting*

There is limited research on the acute physiological responses of competitive weightlifting, due to its brevity. Based off the execution times for the lifts, and with weightlifters exhibiting large percentages of type IIA muscle fibers (Fry *et al*., 2003) it can be assumed that the ATP-PCr system is the primary energy system in use. While fiber type composition can be heavily influenced by genetics, non-genetic factors associated with weightlifting training such as neural and endocrine adaptations may influence the morphology of fiber composition.

Although difficult to measure directly, neural factors have previously been associated with performance features of elite weightlifters (Häkkinen, Komi and Kauhanen, 1986), with high load squat jumps and countermovement jumps correlating well with weightlifting performance ($r$ = 0.76-0.79), potentially due to the stretch shortening rates experienced during the lifts themselves. Neural adaptations have also been associated with increases in strength with a minimal increase in fat-free muscle mass, over a 1 year training period (Fry *et al*., 1994), lending us to think that weightlifting training can increase neural factors such as rate coding and motor unit recruitment.

Endocrine responses to weightlifting programs have shown acute alteration in the testosterone: cortisol ratio (T:C), with significant increases in maximal force (PF) and peak rate of force development (PRFD), with strong correlations ($r$ = -0.83, $r^2$ = 0.69) found between T:C and volume load (Haff *et al*., 2008). This suggests that manipulating load correctly would help elevate the lifters force producing capabilities based on their hormonal status. More long term research looking at endocrine adaptations purported that testosterone levels are augmented after a period of one year of weightlifting training with exposure to one week of overreaching. This suggests that over time the lifter builds a physiological tolerance to overreaching and has a more optimal hormonal state (Fry *et al*., 1994), proving important when considering program design. The biomechanical and physiological requirements of weightlifting suggest that weightlifters require good anaerobic power, and the ability to generate maximum force and power. They need to be able to express these characteristics during both the snatch and C&J, while executing key technical positions to further optimise their chance of success.

**Injury Prevalence**

The loads experienced in weightlifting can far surpass an individual’s bodyweight. Current world records show athletes achieving two and a half times bodyweight for the snatch and over three times bodyweight for the C&J. One would think such feats of strength displayed in a competition would evoke high levels of injury, but relative to other sport weightlifting has shown only a 0.0013 injury rate per 100 hours of training in teenagers (Hamill, 1994). A published source from the IWF, courtesy of Doerr (2012), looked at injury occurrence during European and international events, from 2007 to 2012. His findings illustrate that during this period only 3.2% of 1,414 athletes experienced injuries at European competitions, with a marginally higher occurrence of 3.4% of 1,582 athletes at international events. Further research during competitive periods conducted by Junge *et al* (2009) reported that during the 2008 Olympic games, weightlifting showed one of the highest injury rates amongst all sports, with 89.7% of injuries reported during competition, and only 10.3% in training. The reader should approach these latter findings with caution as only the training conducted in the championship period was accounted for, therefore will not be a good representation of the athletes typical training. Furthermore, the study was governed on response rate of 75.1% from national Olympic committee physicians. Although Junge’s research provides a good insight to injury prevalence in elite weightlifting it does not give us the details required to understand where these injuries occur. Fortunately, the published data from Doerr presented the site spread of injuries in European weightlifting competitions from 2007-2012 as illustrated in table 3

<INSERT TABLE 3 HERE – INJURY SPREAD>

In order for us to better understand the onset of injuries in weightlifting, classifying them into acute and chronic types may help better inform programming and regeneration strategies. Acute injuries by nature tend to be related to muscle and connective tissue strains and sprains (Stone *et al*., 1994). These types of injuries may not stop the athlete from competing, but could result in a brief respite from lifting depending on the severity (Lavallee and Balam, 2010). Chronic injuries are typically insidious, and are often a result of overuse or repetitive strain, thus giving us better insight as to vulnerability of specific sites. Let us consider the results displayed in table 3, where it is apparent that the main site of injury is the elbow. Although not stated as to the type of injury that occurred, one could assume it to be an acute, musculoskeletal injury in which dislocations and tendon ruptures are common, usually as a result from loss of control of the weight during vulnerable positions (Lavallee and Balam, 2010). This is somewhat supported by Junge *et al*'s (2009) results indicating that 5 incidences of injuries in weightlifting at the 2008 Olympic games were dislocations and ruptures. From a technical standpoint the elbows are used to aggressively lock the bar out over head in both the snatch and the jerk. Typically, the elbow is thought to be at greater risk during the snatch than the C&J (Lavallee and Balam, 2010) due to the wider grip and faster rotations around the shoulder. However, the loads experienced in the jerk could have also contributed to the high injury prevalence in the elbow. Alternatively, the risk of injury at the elbow could also be due to anatomical predispositions such as hypermobility, in which case an increase in technical skill would be advantageous as to allow the body to naturally adapt to the load and bar kinematics relative to one's anatomical make up.

Given that weightlifters spend more time training than competing, it is important to address injury prevalence during training. It is in agreement across the literature that weightlifters often experience overuse injuries (Lavallee and Balam, 2010; Junge *et al.,* 2009; Hedrick and Wada, 2008; Calhoon and Fry, 1999). This in turn can cause both acute and chronic injuries, potentially leading to missed training days. A comprehensive study by Calhoon and Fry (1999) on national US weightlifters, documented injury reports over a 6 year period. 64.2 % of athletes had reported training related injuries with the lower back accounting for 23.1% of cases, followed by the knee (19.1%) and shoulder (17.7%). Of importance, the most common injuries were strains, tendinitis and sprains, making up 44.8%, 24.2% and 13 % of injury types, respectively, with strains being the most common in the lower back and shoulder, and tendinitis most common in the knees.  With over 50% of injuries being acute in nature, 87.3 – 95.3% of the primary injury sites returned to training in less than a day. This provides valuable information to coaches and reinforces that overuse injuries prevalent in weightlifting can be relatively minor in nature.

When considering the types and sites of injuries it becomes evident that general conditioning work in vulnerable areas would provide a useful means of pre-habilitation, as well as enhancing performance. With the back being the highest reported injury site it is important to understand that the spinal column itself is not strong enough to bear compression forces from lifting heavy weights (Norris, 2008,pg 34.). Avoiding compression forces is somewhat unavoidable, as a primary method of developing leg strength in weightlifting is through back squats, with elite lifters regularly squatting over three times bodyweight. The high torques generated during weightlifting training must be distributed to the connective tissues and muscles surrounding the spine, thus if these muscles are not sufficiently trained the likelihood and severity of injury can be high (Norris, 2008,pg 34.). It is therefore advised that additional strengthening of the torso, specifically the back extensors such as the erector spinae would prove advantageous to lifters to cope with the torques experienced during training and competition, as well as serve a functional purpose of better transmitting force from the floor to the barbell. Second to this the chronic injury experienced at the knee is likely due to the constant deep squat patterns associated with weightlifting, thus providing additional anterior shearing forces on the tibio-femoral joint (Gullett, *et al*., 2008). Although this is somewhat unavoidable, we suggest that the volumes of squats and full lifts are monitored, and are appropriately loaded with particular attention to the clean as unpublished data from Stone 1980-1983 suggested that the more frequently cleans are performed at 90% or above, the more training days missed (Stone *et al*., 1994).

Sufficient conditioning for the upper extremities such as the shoulder and elbow will help assist in stabilising the bar overhead during the snatch and jerk. The complexity and freedom of movement at the shoulder makes it a vulnerable thus it is warranted to spend time working on general shoulder health, including strength, mobility and stability, which can generally be achieved through correct lifting technique and traditional assistance exercises discussed later on in this chapter. It is evident from the literature that weightlifting, carries a risk of injury. It is repetitive in nature and constantly stresses the body with high loads and is therefore suggested that weightlifting movements are performed with good technique, under supervision of an accredited coach. Secondly, the programme should be appropriately structured with the inclusion of pre-habilitative or assistance exercises with volumes and loads monitored, thus lessening the likelihood of overuse injuries.

**Fitness Testing Battery**

It goes without saying that the ability and progress of a weightlifter can simply be judged on the weight they achieve during the snatch and C&J. It is therefore not uncommon practice to have lifters go to 1RM during the end of a training phase, with some country's advocating daily maxes as to dictate the loads used for training (Illiou, 1993 and Ganev, 2003, cited in Garhammer and Takano, 2003, p. 512.). Non-direct measures of the lifts have also been conducted utilising isometric and dynamic pulls as well as various jump tests. The variables extrapolated from these include; peak force (N), peak RFD ($N.^{s-1}$) and power output (W) and have shown to have moderate to strong relationships (*r* = 0.47-0.83) with the snatch, clean and competition total (Haff *et al*., 2005; Häkkinen, Komi, and Kauhanen, 1986). This provides us with good justification to utilise these tests, but the practically maybe limited due to the requirements of expensive equipment.

More field based tests have been reported in weightlifting, primarily in talent identification. Research from Fry *et al* (2006) established that body mass, vertical jump, relative fat, grip strength and torso angle during an overhead squat classified 84.35% of national junior's competitors as either elite or non-elite. This proves useful as we know power is a desirable characteristic for a weightlifter, and that lean muscle mass would contribute to its production. Therefore, utilising jumps could help determine whether an increase in power has been achieved during a training phase.

Another method of better informing program design is utilising percentage variances between lifts. Although some variations may exist between lifters it has been long suggested that the snatch and the C&J should be within a certain percentage of one another, or of other key lifts, as outlined in table 4. This however should only be used as a guideline and any divergence of these numbers is not indicative of problems (Everett, 2009, pp 239).

<TABLE 4 HERE – PERCENTAGE RELATIONSHIP>

To conclude we have presented both lab  and field based (table 5) testing batteries to assess qualities associated to weightlifting. However, it is important for the reader to understand that these tests can only help better understand the requirements of training and may not represent a direct increase in the snatch or C&J.

<TABLE 5 HERE – LAB/FIELD TESTING>

**Programming**

The purpose of program design is to deliberately manipulate training variables to provide adequate stress to the body as to elicit a desired outcome (Everett, 2009, p 231). Before discussing the process of programming some key definitions must be understood as outlined in table 6. Three primary principles need to be considered when designing a weightlifting program; specificity of exercise, overload and variability (Garhammer and Takano, 2003). Specificity refers to lifts which replicate or are similar to that of the competitive lifts as outlined in table 7. Overload relates to an increase in stress to the body through elevating intensity and/or volume. Finally, variability relates to the composition of training load to avoid maladaptation (Garhammer and Takano, 2003). The organisation of training will largely affect the desired outcome, and it is therefore prudent the reader understands the concepts of structuring a training programme.

<INSERT TABLE 6 HERE – PROGRAMMING DEFINITIONS>

<INSERT TABLE 7 HERE  - EXERCISE DERIVATIVES>

*Structuring a training cycle*

In weightlifting the primary stressor with which we’re concerned is intensity. The long term increase in average intensity is progressive overload. All training creates local and systemic fatigue along with increased performance potential through responsive adaptation. This adaptation will not be immediate, and will only be measurable after the associated fatigue of the training in question has abated. In order to achieve positive adaptation at specific time points, periodic manipulation of volume, intensity and exercise selection must be planned. This is known as periodization (Haff *et al*., 2004). Typically, one would start designing a macrocycle with specific competitions in mind to peak for. Over the course of a macrocycle, on average, volume will decrease and exercise specificity and intensity will increase. A macrocycle will begin with one or more preparatory mesocycles in which strength and/or hypertrophy is emphasized utilising lifts such as squats, pulls and presses (Programme 1). The competition lifts and their variants are employed with relatively low frequency (1-2 exercises per session) and intensity (60-70% 1RM), and higher repetitions per set (4-6). The final mesocycle will be a competition phase (typically the final 4-6 weeks) in which the competition lifts are emphasized, with higher frequency (2-4 exercises per session) and intensity (80%+), and lower repetitions per set (1-3). At this point strength work is minimized (1-2 exercises per session) and largely used to maintain existing strength rather than develop it (Programme 2). The models of periodization utilised during preparatory and competition cycles can vary depending on the desired outcome.

<INSERT PROGRAMME 1 HERE – PREP>

<INSERT PROGRAMME 2 HERE – COMP>

The idea of the preparatory phase is to allow the lifter to build a physiological tolerance to the high volume loads associated with the more advanced phases and would therefore utilise basic and intermediate periodization models. The basic model would entail the sole development of a single biomotor during a mesocycle. The volume load will be uniform in nature with an inverse relationship between volume and intensity as a new mesocycle is started (Graph 1). An intermediate model as would display summations during each mesocycle with a linear increase in volume load for three weeks followed by an unload week during the fourth as to allow for recovery (Graph 2). Each week could have a different biomotor focus, thus allowing for greater variability in training. This is useful for those who present a smaller window of adaptation thus requiring the additional variability, such as recreational weightlifters. The loading schematics from basic and intermediate periodisation can be useful when looking to develop work capacity in the legs for example, so they are able to tolerate higher volume loads later experienced in their lifting career. Typically, as the training year advances the type of model used could also be advanced. The advanced model (also termed conjugate model) advocates accumulation blocks and restitution blocks, where a specific biomotor is overloaded for a 2-3 weeks and is followed by a lower load, equal length mesocycle of a secondary biomotor (e.g., Strength accumulation phase followed by a power restitution phase). This model of periodisation promotes purposeful overreaching a phenomena in which significant fatigue and concurrent decrease in performance is experienced (Turner, 2011). It is during the restitution block in which the pervious biomotor will super compensate as a virtue of a delayed training effect. This can be achieved by manipulating the frequency of training during each block. This model may prove useful when approaching a competition; however, to apply these interventions requires high levels of skilful loading and monitoring, as to avoid overtraining.

<INSERT GRAPH 1 HERE – BASIC MODEL.

<INSERT GRAPH 2 HERE – INTERMEDIATE MODEL>

It is worth mentioning that non-traditional methods of periodization such as daily undulating periodization (DUP) can also be utilised for weightlifters. Here the volume and intensity is manipulated daily thus focusing on a different biomotor. This method of periodisation is extremely adaptive and is possibly more suited for the amateur weightlifter that may not be able to train to such a rigid schedule which the traditional models require. This method however has been shown to not be as effective as the traditional method when looking to increase strength (Haff *et al*., 2012). The strong correlation that exists between volume load and T:C suggests that manipulating volume load correctly may elevate the lifters force generating capabilities (Haff *et al*., 2008). Secondly volume loads experienced during purposeful overreaching may help to develop a physiological tolerance over time as found after 1 years weightlifting training (Fry *et al*., 1994).

Mesocycles to elicit the desired performance effect, such as strength and power will typically culminate with a tapering period. The taper refers to a reduction in volume load in the build up to a competition, with the primary objective to dissipate accumulated fatigue from the previous mesocycle (Turner, 2011). There are multiple methods of tapering; linear, a small decrease in volume loads every session; step, a large decrease in volume load on the first day of the taper, with maintenance of that volume load until competition; exponential, where volume load is decreases at a proportional rate to its current value; and a 2 phase taper, a classical reduction in volume load with a moderate increase closely coming up to competition (Turner, 2011). Information from a meta-analysis (Bosquet *et al*., 2007) revealed that the optimal taper is a two week exponential taper, with a decrease in volume of between 41-60%, whilst maintaining intensity and frequency. This however may not fit all athletes, and the accumulated fatigue from the previous mesocycle must be considered as this may largely dictate the reduction in volume load and the period and type of taper utilised. That is to say the greater accumulated fatigue the greater the taper.

*Developing strength and power*

Neurological adaptation is the primary manner in which weightlifters improve strength and power over the long term, and the reason why a lifter can continue to gain strength over a long period of time without gaining weight or increasing in size. Training works to improve motor unit recruitment, rate coding, synchronization, golgi tendon organ inhibition, and intermuscular coordination to allow the weightlifter to produce the greatest amount of force and power with a given mass of muscle. Given the high importance of the 1st pull, 2nd pull and a fast drop under speed, it is pertinent that exercise selection and intensity look to improve these variables through kinematic and kinetic similarities to the full lifts, with the addition of utilising exercises that best improve general strength and power.

The intensities of weightlifting specific exercises will vary depending on the model used, however the volume distribution of the exercises will be dependent on the phase of training (Graph 3a & 3b). The development of leg strength for weightlifting is pivotal, with strong correlations found between 1RM squat and snatch and clean ($r$ = 0.94 and 0.95, respectively) (Stone *et al.*, 2005). This provides us with a strong rationale to spend time in the preparatory phase developing leg strength with maintenance in the competitive phase, and a shift to front squats to elicit specific adaptation transferable to the clean. This transfer of leg strength should also help develop the back extensors and stabilisers as both back and front squats have shown to have muscles activities of over 40% relative to maximal voluntary contraction in the erector spinae (Gullet *et al*., 2008), potentially reducing the risk of back injury. Coupled with specific 1st and 2nd pull drills (Halted 1st pull and pulls), this should enhance one's ability to optimise bar path during this phase and perform greater work, since traditional pulls can be performed at loads 10-40% greater than that of the lifters maximum competitive lifts (Garhammer and Takano, 2003). That said a review by Suchomel, Comfort and Lake (2017) reviewed weightlifting derivatives relative to barbell velocity. They state that the exercises prescribed can vary in load to meet the specific demands of the training phase thus enhancing different aspect of the force-velocity curve.

<INSERT GRAPH 3A AND 3B HERE – LIFT RATIO>

Developing vertical velocity on the bar and catch speed is related to the power we can produce during the 2nd pull as well as how quickly one can drop in the catch position. In order to develop these qualities, an emphasis on derivatives from the hang position, or power variants maybe advantageous at loads of 70-85% (Garhammer and Takano, 2003). Alternatively, Comfort, Udall and Jones (2012) had found that peak power during mid-thigh clean pulls was developed at 40% with peak force developed at 140% of clean 1RM, so potentially overloading this power position at both ends of the force curve may help and individual become stronger and faster during the 2nd pull. During the competitive phase it is recommended that lifters spend more time on the full lifts, as to be able to utilise the developed strengths and skills in the previous phase. A study conducted by Gonzalez-Badillo, Izquierdo and Gorostiaga, E.M (2006), concluded that moderate volumes (91 reps) of high relative intensity (90%) on competition lifts and squats, over 10 weeks produced greater weightlifting performance enhancement compared to low (44 reps) and high volumes (182 reps) of high relative intensity.

To conclude, the organisation of training should consider the primary objective of each mesocycle approaching the competition. We suggest that working backward from a competition date may help better organise the allocations of specific mesocycles. Developing a lifters weakness, both physical and technical, and maintaining their strengths will be determined by the exercise selection and intensity that is prescribed. Typically loads of 70-90% over the course of the preparatory and competitive phase is most beneficial, with occasional supramaximal loads for partial movements, such as pulls. This overload with additional variability during each mesocycle should elicit the greatest enhancement in weightlifting performance.

**Conclusion**

The sport of weightlifting requires high amounts of muscular power, strength and skill. It is evident that the most successful weightlifters are able to display a rearward movement of the bar during the $1^{st}$ pull creating a steady bar velocity which increases exponentially during the $2^{nd}$ pull. This allows the lifter to keep the bar close to the body and transfer mechanical energy to the bar, thus contributing to greater vertical bar displacement allowing the lifter sufficient time to drop under and receive the bar in the catch. The primary contributing factors to these preferred bar kinetics and kinematics stem from greater work being carried out during the $1^{st}$ pull with a decrement evident during the $2^{nd}$ pull, however power production is far greater during the $2^{nd}$ pull as a result of an increase in hip, knee and ankle angular displacement, furthered by a contribution of the stretch reflex.

Weightlifting has shown high levels of injury rates when compared to other Olympic sports, particularly in the elbow, but this may be due to individuals attempting higher loads than usual with more at stake. Secondly injury rates in training are typically experienced in the lower back which tends to be acute in nature and result in a loss of less than one day of training. Commonly strains are the most experienced type of injury, and are typically down to over use, thus showing the importance of organising rest days and variability into the program. In terms of programing we must consider the exercise selection, volume and intensity prescribed at different periods, namely the preparatory and competitive phase. Typically, greater assistance and strength work will be performed during the preparatory phase with a greater emphasis on squatting and pulling strength, whereas the completive phase would focus on maintaining these strength qualities and transferring them to the competitive lifts, ready for competition.

With weightlifting being multifactorial in nature one can enhance their chance of success by understanding the key technical aspects of the lifts and the exercises associated with their development. We therefore suggest that adaptations should be made one's physical condition and capabilities, as the ability to perform the competitive lifts with appropriate competency will ensure the greatest chance of success in the future.

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**Equation 1** – The Sinclair coefficient (S.C.)

$$S.C. = \begin{cases} 10^{AX^2} \; (x \leq b) \\ 1 \; (x > b) \end{cases}$$

$$\text{Where } X = \log_{10}\left(\frac{x}{b}\right)$$

$\mathcal{X} = athlete\ bodyweight\ (kg)$

| | Men | Women |
|---|---|---|
| *A* | 0.751945030 | 0.783497476 |
| *b* | 175.508 kg | 153.655 kg |


(a) Set position


(b) End of first pull


(c) Power position


(d) End of second pull


(e) Peak bar height


(f) Catch


(g) recovery

**Figure 1 –** Snatch phases.


(a) Set position

(b) End of first pull

(c) Power position

(d) Second pull

(e) Peak bar height

(f) Catch

(g) Recovery

**Figure 2 –** Clean phases.

(a) Set

(b) Dip

(c) Drive and split

(d) Catch

(e) Recovery

**Figure 3 –** Split jerk phases


(a) Set position (b) End of first pull (c) Power position (d) Second pull

(e) Peak bar height (f) Catch (g) Recovery

**Figure 2 –** Clean phases.


(a) Set


(b) Dip


(c) Drive and split


(d) Catch

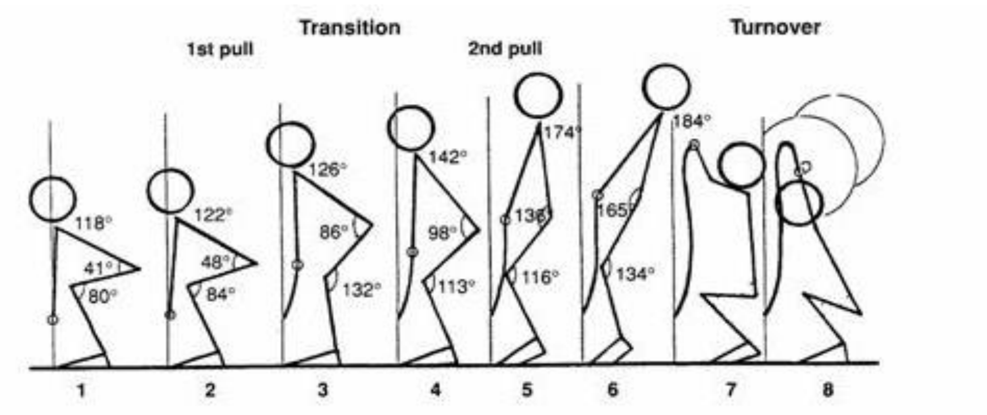

(e) Recovery

**Figure 3 –** Split jerk phases


**Figure 4** – Typical shallow “S” bar trajectory displayed in the snatch and the clean.

Lifter A

Shalamanov
145.5kg (WR)
EC 1986




Lifter B

Krastev
207.5kg
EC 1986

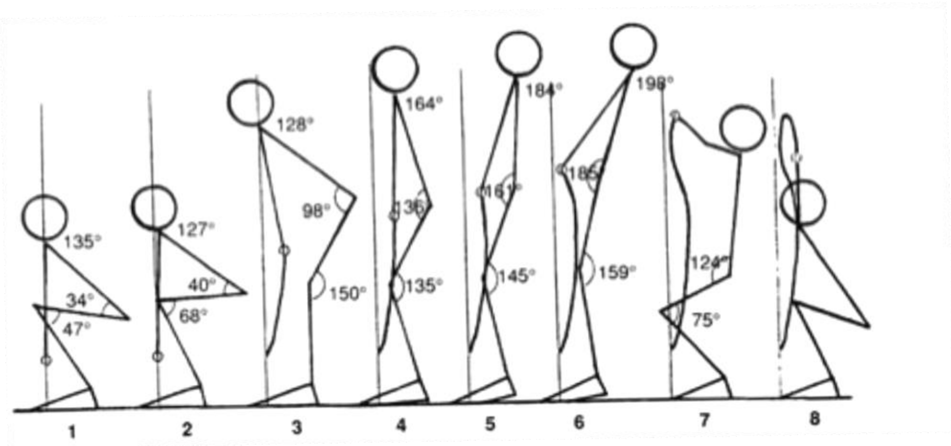



**Figure 5** – Variation between taller (a) and shorter (b) lifter set up. Adapted from unpublished research of Lippmann and Klaiber (1986), presented in Bartonietz (1996).

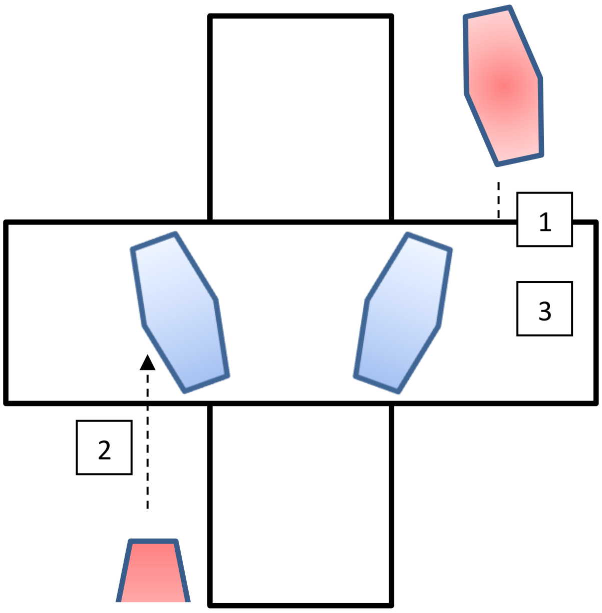
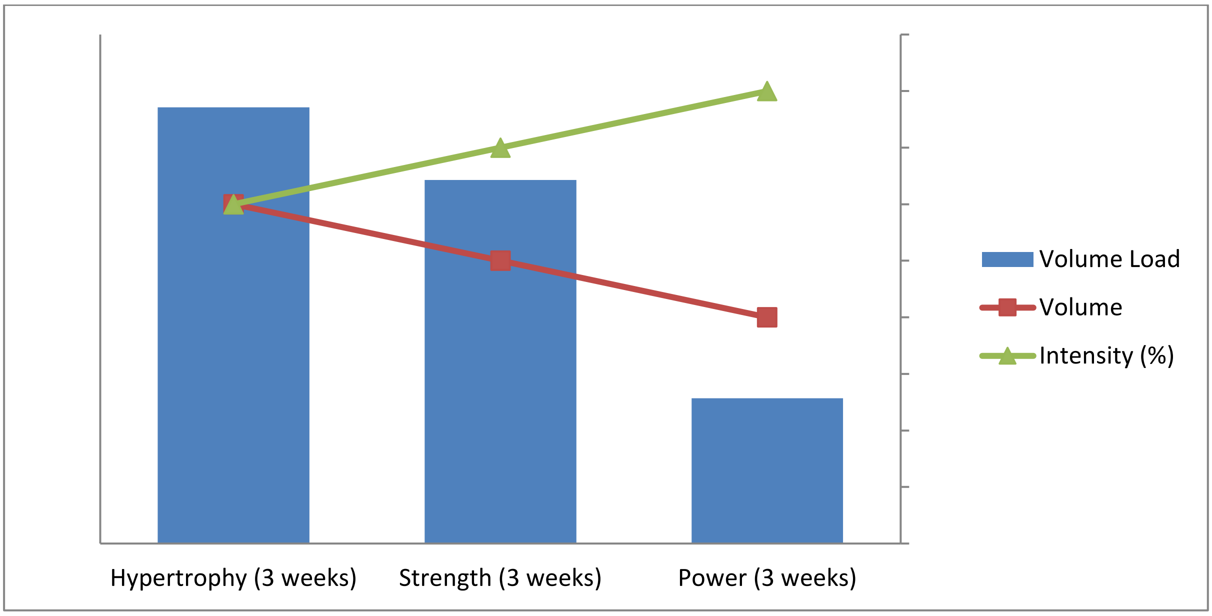
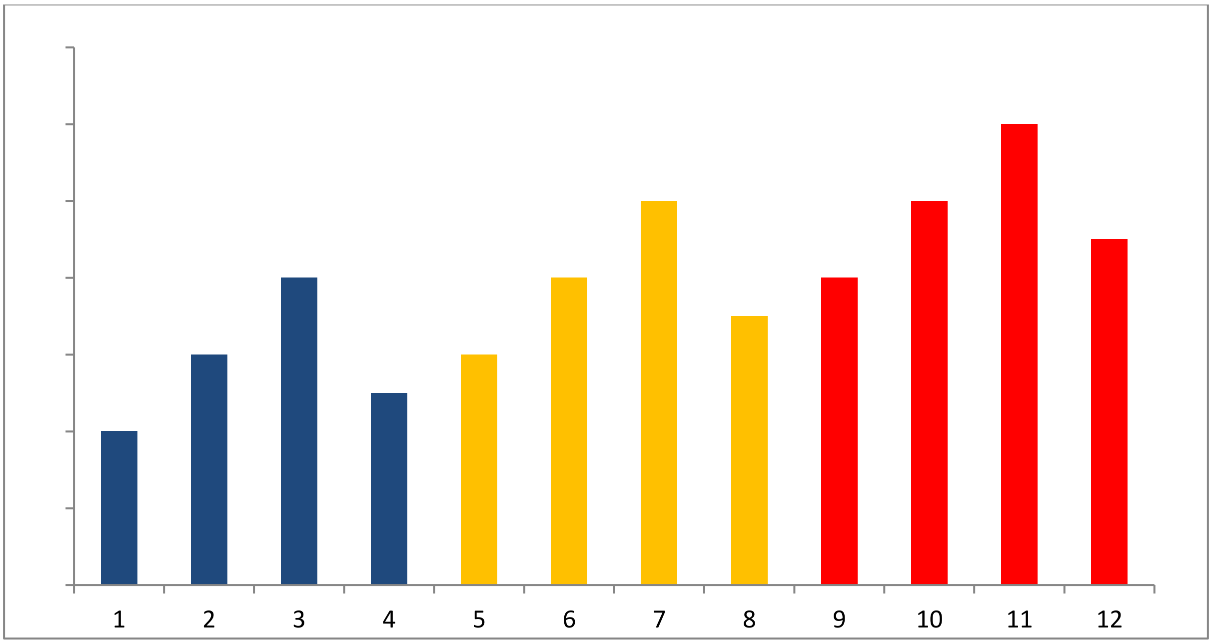



**Figure 6** – Foot position for the jerk. Blue displays the set and red displays the catch. The arrows depicted represent the recovery steps for each foot.




**Graph 1** – Basic periodization model




**Graph 2** – Intermediate summated periodization model.

**Table 1** – Senior and junior weight class categories for males and females.

| Term | Definition | Equation (Unit) | Example |
|---|---|---|---|

| **Male** | **Female** |
|---|---|
| 56kg ( ≤ 56.00kg) | 48kg ( ≤ 48.00kg) |
| 62kg (56.01 – 62.00kg) | 53kg (48.01 – 53.00kg) |
| 69kg (62.01 – 69.00kg) | 58kg (53.01 – 58.00kg) |
| 77kg (69.01 – 77.00kg) | 63kg (58.01 – 63.00kg) |
| 85kg (77.01 – 85.00kg) | 69kg (63.01 – 69.00kg) |
| 94kg (85.01 – 94.00kg) | 75kg (69.01 – 75.00kg) |
| 105kg (94.01 – 105.00kg) | 90kg (75.01 – 90.00kg) |
| +105kg ( ≥ 105.01kg) | +90kg ( ≥ 90.01kg) |

| | | | |
|---|---|---|---|
| Work | Work (J) results when force (N) acts upon the barbell to cause displacement. | Work = Force × displacement (Joules)<br>W = *Fd* (J) | High forces are generated to displace the bar during the 1st pull, thus more work is performed to overcome the barbells inertia. |
| Power | This is the rate at which work (J) is done, thus is a time based quantity. | Power = Work / time (Watts)<br>P = W/t (W) | The 1st pull is a slow movement thus producing less power, whereas the 2nd pull is performed explosively at a faster rate thus producing more power. |
| Mechanical energy | Energy acquired by the barbell as a result of the lifters work. | Mechanical energy = Kinetic energy + Potential energy (Joules)<br><br>M.E = $\frac{1}{2}mv^2 + mgh$<br>Where m is mass, *v* is velocity, g is gravity and h is height. | If low amounts of work is conducted during the 1st pull and the bar is not drawn back, there will be an increase in mechanical energy during the 2nd pull thus potentially being deleterious to the lift. |

**Table 2** – Key biomechanical terminology.

**Table 3** – Injury sites and total number of injuries during the periods of 2007-2012 from the European weightlifting championships (EWC). *Adapted from Doerr (2012)*.

| **Anatomical Region** | **Female** | **Male** | **Total** |
|---|---|---|---|
| Head | *1* | | *1* |
| C-Spine | *1* | | *1* |
| Hand & Finger | | | |
| Elbow | *5* | *7* | *12* |
| Shoulder | *1* | *3* | *4* |
| Back | *2* | *4* | *6* |
| Belly | *1* | | *1* |
| Hip | | *2* | *2* |
| Thigh | | *12* | *12* |
| Knee | | *3* | *3* |
| Lower limb | | *3* | *3* |
| Foot | | | |
| **TOTAL** | **11** | **34** | **45** |

**Table 4** – Suggested percentage ranges lifts should fall within of one another. Adapted from Everett (2009,pg. 239).

| **Primary lift** | **Of lift** | **Percentage** |
|---|---|---|
| Snatch | Clean and Jerk | 80-85% |
| Power Snatch | Snatch | 80-85% |
| Power Clean | Clean | 80-85% |
| Front Squat | Back Squat | 85-90% |

**Table 5** – Field and lab based performance testing battery for weightlifting

| | **Characteristic** | **Test** | **Equipment** | **Variable** |
|---|---|---|---|---|
| | *Strength* | Snatch<br>Clean<br>Back squat<br>Front Squat<br>Deadlift | Barbell<br>Weight plates<br><br>Tape measure, iPhone + Powerlift application | Absolute load (Kg)<br><br>Predicted 1RM based on barbell velocity profile. |
| **Field Tests** | *Power* | Counter movement jump with arm swing (Sargent jump)<br><br>Countermovement jump profiling (unloaded and loaded) | Chalk<br>Wall<br><br>iPhone + MyJump application | Absolute height (cm)<br><br>Jump height, predicted peak force, predicted peak power, optimal force-velocity profile. |
| | *Strength* | Clean grip Isometric mid-thigh pull at an angle of 141 ± 10° at the knee and 124 ± 11° at the hip. Alternatively | Isometric rig<br>Cold steel bar<br>Force plate | Peak force (N)<br>PRFD (N) |

| | | | | |
|---|---|---|---|---|
| **Lab Tests** | | angles can be established from the power position during an actual lift.*<br><br>*Freeze frame required. | Laptop<br>Goniometer<br>Video camera (optional)* | |
| | *Power* | Counter movement jump. | Force plate | Jump height (cm)<br>Peak force (N)<br>Impulse (N.s)<br>Peak Power (W) |

**Table 6** - Key terminology and definitions for programming.

| **Term** | **Definition** |
|---|---|
| Macro cycle | Typically refers to the complete training cycle that can span over a year or between major competitions. |
| Mesocycle | Relates to a phase of training, lasting between 4-6 weeks or more. |
| Microcycle | The smallest phase of training generally referring to one week. |
| Intensity | This relates to the difficulty of the exercise and generally refers to a percentage of your one repetition maximum (1RM). |
| Volume | This is the culmination of repetitions performed in a session, micro- , meso- or macro-cycle. |
| Volume Load | This refers to the work or tonnage lifted during a session, micro- , meso- or macro-cycle. This is typically calculated by multiplying the volume by the absolute intensity (total reps x total load lifted) |

**Table 7** – Weightlifting specific exercises

| Snatch | Clean | Jerk | General Assistance Exercises |
|---|---|---|---|
| Over head Squat<br>Snatch Balance<br>Snatch from power position*<br>Hang Snatch*<br>Halted Snatch 1st Pull<br>Snatch Pull<br>Power Snatch | Front Squat<br>Clean from power position*<br>Hang clean*<br>Halted clean 1st pull<br>Clean Pull<br>Power Clean | Over head Press<br>Push Press<br>Jerk Balance<br>Behind neck Jerk | Back Squat<br>Deadlift<br>Good Morning<br>Romanian Deadlift (RDL)<br>Bent Over Row |

*Refers to power snatch or power clean variations of the full catch.