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Biomechanical differences in the weightlifting snatch between successful and unsuccessful lifts

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BIOMECHANICAL DIFFERENCES IN THE WEIGHTLIFTING SNATCH BETWEEN SUCCESSFUL AND UNSUCCESSFUL LIFTS

An Abstract of a Thesis

Submitted

in Partial Fulfillment

of the Requirements for the Degree

Master of Arts

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ABSTRACT

The purpose of this study was to determine what differences exist between several kinematic variables between failed and successful attempts in the snatch lift. Six female Weightlifters at the 2015 American open were measured for kinematic variables via videotape during competition. The results show that differences existed in the angle of the shoulder at peak barbell height and the catch height, along with the amount of separation between the lifter and barbell at peak height. Significant differences were also found at the angle between the barbell and lifter center of mass. This study was a first step toward understanding the importance of the lifter's ability to quickly and accurately pull themselves under the barbell. A better understanding of this association may help to improve coaches' abilities to develop drills to improve consistency in barbell path.

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CHAPTER I

INTRODUCTION

The sport of Weightlifting has been dominated throughout its history by individuals that are able do display superior physical power and technical mastery. These two aspects seem to lie on opposite ends of the spectrum. Logically, there are weaker individuals that have more perfected positions when performing the lifts. They are able to be successful by having a great efficiency with the strength they possess. Other individuals seem to have great strength, which allows their technique to have a wider margin of error and still able to successfully complete lifts.

At the elite/international level this spectrum still holds true, but with a much narrower margin in comparison to novice lifters. Examples of this throughout history have been Chinese Weightlifters falling more toward the technical precision side of the spectrum, and Bulgarian Weightlifters falling on the strength surplus portion of the spectrum (Simmons, 2007). Regardless, throughout history these teams have both been extremely successful in this sport on the international platform.

Much research exists on how to improve general strength, even at the highest level of sport, but what is lacking in the literature is research describing the technical flaws of unsuccessful lifts, besides improper height of the barbell from the pulling phases. Some literature suggests that the highest correlation between successful and unsuccessful lifts is the angle of the barbell during the first pull and displacements in barbell trajectory (Musser, Garhammer, Rozenek, Crussemeyer, & Vargas, 2014; Gourgoulis, Aggeloussis, Garas, & Mavromatis, 2009). But before this is examined further, the anatomy of the two events that make up the sport of Weightlifting must be discussed.

The movements of Weightlifting are the snatch and the clean and jerk. Each of these movements require an explosive generation of force in order to get the barbell from the floor to its successful overhead, arms locked-out position. The snatch requires a single movement to bring the barbell to the final position. The clean and jerk requires a two-part movement to get the barbell to its final overhead position (Stone, Pierce, Sands, & Stone, 2006). The first movement, known as the clean, takes the barbell from the ground to a “racked position” with the barbell resting on the clavicles. From here, the barbell is thrusted overhead in the final locked-out position, known as the jerk. The lifter executes these movements by accelerating the weight upward during pulling/driving phases and dropping underneath the barbell, using the barbells momentum to the lifters advantage by not needing to pull the barbell as high (DeWeese, Serrano, Scruggs, & Sams, 2012).

Since the clean and jerk is a two part movement, it is difficult to specifically identify what produces poor positions. Focusing on the snatch, literature has suggested that the highest correlation to successful lifts is maintaining positioning on first pull of the lift. This is the portion of the lift where the lifter breaks the barbell from the floor and begins accelerating the barbell vertically till this phase ends at knee height (Kipp, Harris, & Sabick, 2013). The literature suggests that the lifter gets pulled out of position in the first pull because this phase of the lift requires the greatest force output to change the weight from a static load, on the floor to a dynamic load, accelerating the barbell vertically (Simmons, 2007). In all the other phases, the barbell is already dynamically in motion, which is easier to manipulate. With the small amount of literature investigating variables that effect the success of the snatch in elite lifters, there are many unanswered questions about how this pertains to the whole Weightlifting community.

Statement of Problem

The purpose of this study was to determine if kinematic differences existed between successful and unsuccessful attempts at the same loads by the same lifters at an intermediate level competition. This information is needed in order to develop a better understanding of proper pull angle for non-elite lifters, along with the average margin of error one can have and still successfully complete the lift.

Null Hypothesis

There will be no kinematic differences between successful and unsuccessful attempts in the snatch.

Significance of the Study

At the elite level in the sport of Weightlifting oftentimes these competitors have a surplus of pulling strength eliminating pulling height to be a rationale for missed attempts. Specifically in the snatch movement there is much more importance upon body position throughout the movement due to the barbell traveling the entire distance from the ground to overhead in one ballistic movement. Some research has found that proper positioning in the first pull of the snatch has the highest correlation to successful lifts (Ho, Williams, Wilson, & Meehan, 2011). Research needs to be taken a step further to understand the variables that primarily influence failure, which in turn could give the coach feedback that their trained eyes may have missed, and to what degree this correction should be made. The variables that need to be assessed are the horizontal displacements in the pull, and the variables at play when the lifter switches from pulling to catching the barbell. This may be a first stab in the right direction of where drills can be developed to help less skilled coaches and athletes in Weightlifting.

Delimitations

In this study, data were obtained from subjects completing successful and unsuccessful lifts near maximal effort. This intensity is necessary because the subject needs to miss the lift by accident, and it is much more likely to occur at weights closer to the 1RM (Stone, O'Bryant, Williams, Johnson, & Pierce, 1998). A Weightlifting competition would produce ideal conditions for data collection. The data collection process would need two high-definition (1080p) video cameras (JVC GC-PX1, Victor Corporation, Tokyo, Japan) recording at 60 Hz, set at various angles to the competition platform. A lifter would qualify as a subject for this study only if there was both an unsuccessful and successful snatch at the same load. The video data were digitized using MaxTraq (Innovision Systems, Inc., Columbiaville, MI) and derived 3-D data from the two cameras with the use of a calibration tool to yield 3D data. The data was then processed using custom programs from MATLAB (Mathworks, Natick, MA). Ideally, the skill level of the competitors should be as high as possible, but is not a necessity. Novice lifters have a greater margin of error in technique that can still result in success. This is due to the load being relatively light enough, in comparison to their absolute strength level, to allow for greater technical inefficiency. Whereas, the trend will show a smaller margins of error for more experienced Weightlifters with more efficient technique.

Limitations

Due to the range of weight classes and experience in Weightlifting meets, the sample that is analyzed may not reflect the rest of that specific skill level due to anthropometric differences. The sample examined is a lightweight female class, which also may not reflect the kinematic variables of male Weightlifters. Ideally, obtaining kinetic variables would give more of an unabridged perspective of unsuccessful snatches, but would require additional force plate data. In order to uphold anonymity at a public event, video camera data is all that can be obtained.

Assumptions

Since this is purely an observational study, many of the assumptions have to be made in the procedures of running instrumentation and processing data. Some of the assumptions may include the setup of the collection. This entails proper marker placement and the cameras not being moved after calibration. Other assumptions can be made in the processing of the data. The synchronization of the two cameras to be exactly the same. The tool used for calibration needs to be properly calibrated. Lastly, in the digitizing process of the video there needs to be proper and consistent marks by the researchers.

<u>Definition of Terms</u>

Ground Reaction Force (GRF)- A three-component vector representing the forces in the vertical, anterior-posterior, and medial-lateral planes in relation to the ground (Lei, Gao, et al., 2006)

Snatch- Lifting a barbell from the floor to arm's length overhead in one continuous motion. Although this same definition may be used for the power snatch, an important difference between the two is that of the finish or "catch" position. The power snatch usually is defined as a catch position where the thigh is above a 90 degree angle in comparison to vertical. (Waller, Townsend, & Gattone, 2007)

First pull- The 1st pull occurs from the moment of separation (MOS) of the bar from the floor and continues until the bar reaches the top of the knee, or for some athletes, just above the knee. (Farve & Peterson, 2012)

Power- The ability of the neuromuscular system to perform work over a given time period or, alternatively, the product of force that can be exerted at a given velocity of movement. (Hori, Newton, Nosaka, & Stone, 2005)

Triple extension- refers to the movement that occurs when the ankle is dorsiflexed; the knee and hip are flexed in a static position; and then rapidly the ankle is plantar flexed and the knee and hip are extended. (Waller et al., 2007)

Speed Strength- Any capacity that contains both a force (strength) and speed component to muscular actions. (Hydock, 2001)

Relative Intensity- is the percentage of the 1RM for a given exercise (lift). (Stone et al., 2006)

Load- Reference to the total weight of the barbell (DeWeese et al., 2012)

Stretch-shortening cycle (Stretch-reflex)- If a muscle shortens immediately after a stretch the force and power output increases, and energy expenditure decreases (Zatsiorsky & Kraemer, 2006)

CHAPTER II

REVIEW OF RELATED LITERATURE

Both Weightlifting movements, the snatch and the clean and jerk, would be considered some of the most technical movements in lifting (Stone et al., 2006). This is due to these exercises requiring high peak forces to be applied to the barbell in order to catch the barbell in a fully squatted position within fractions of a second. With the technique evolving throughout the history of the sport of Weightlifting, there have been voids in the literature toward a universal technique that can be applied to any prospective athlete. For this reason, it is necessary to take some initial steps toward debunking a universal technique. These initial steps should be focused on isolating primary factors that contribute to unsuccessful lifts. This literature review is aimed at the examination of the sport of Weightlifting by discussing the history of the sport, the phases of the snatch and clean and jerk, general snatch technique, anthropometry implications on technique, and barbell trajectory.

History of Weightlifting

The start of the modern Weightlifting began in the mid-1800s. Many fitness clubs sprang up in Europe at the time and implemented these movements along with other strength exercises. Prior to 1896, there was no specific technique to complete the events as long as the barbell ended up in the final overhead, locked-out position. In the 1896 Greek Olympics there was a tie between two competitors, but a winner needed to be decided to award that particular lift. So the prince of Greece ruled that one competitor won due to “better style” (Hancock, Wyatt, & Kilgore, 2012). This was appealed by the loser of the tie without success, but did bring the change of Weightlifting rules including a criteria for the judging of each event.

The sport of Weightlifting consisted of more events than the snatch and clean and jerk, which are currently the only two events in Weightlifting. These were mostly one-armed variations to the snatch and clean and jerk, and the other lift which managed to stay in competition the longest was the clean and strict press. The one-armed variations of the snatch and clean and jerk were performed using the same barbell as the other lifts. This added a level of difficulty in the balance and grip strength of the Weightlifter. Barbells helped to accommodate the grip by putting a strip of knurling on center of the barbell. This also gave the Weightlifter a rough idea within a few inches where to put his hand to have proper balance overhead. The one-armed lifts were removed from competition in 1925. Even though single-arm Weightlifting movements are rarely used on a barbell, the knurling in the center remains on most barbells since it still is a helpful aid to the Weightlifter aligning his or her body (Stone et al., 2006).

The clean and press was final event to be removed from competition almost 50 years later in 1972. There were a couple of contributing factors for this movement getting removed from competition. First, was the difficulty of the judging for the technique of the lift. In the clean and press, the difficulty of judging came during the press. The rule did not allow knee bend, which would give the lifter additional assistance with the stretch-reflex and be classified as a push-press instead of a strict press. Instead, the lifters cleverly developed a technique that involved the combination of hyperextension of the lumbar spine and oscillation of the "springy" barbell. Not only did this technique make it difficult to judge the press, but is also suspected as the primary reason why there was a high rate of micro-fractures in Weightlifters spines during this time period (Stone et al., 2006). Studies prior to 1972 examining injury rates and back health of Weightlifters show an inflated rate of micro-fractures, which fuels some of the fallacy that modern Weightlifting is associated with high injury rates (Gourgoulis et al., 2009). Studies in recent years on the modern Weightlifting movements, and have seen a dramatic drop in injuries that now reflect many other modern day sports injury levels.

A significant change in technique for the snatch and clean and jerk occurred when former American Olympic Champion, Tommy Kono developed the squat catch for both the snatch and the clean and jerk (Fair, 1987). Prior to the balanced squat-style catch, almost entirely practiced today, the rest of the world was catching the barbell in a deep split stance. Since Tommy Kono was extremely successful in his career, 1952-1964, largely due to this technique, the competition began switching to this style soon after, until it was the primary technique seen in competition. The advantage of this technique was the ability of the lifters to get into a deeper position while squatting compared to the depth of a split stance. Also, from the deepest position, it was easier to squat the weight up with the feet balanced as opposed to an extremely long split position.

The one of the last large events in Weightlifting history has been the inclusion of females into the sport, specifically on an international platform. In 1987, the first World Championship was open to a female division, but it was not until 2000 in Sydney, Australia where women were able to compete in the Olympic Games (Stone et al., 2006). This competition did not feature many high level female Weightlifters, but has gained enormous popularity around the world since then. The abilities of the females has only recently been realized since many of the first Olympic level competitors had only had a few years of training at most, in comparison to the men's division that has a rigorous system in place, beginning training around the age of 8 years old (Fair, 1987).

Weightlifting has been perfecting the rules and techniques through much trial and error. This includes the reduction down to the two movements in competition that are most significant. This has cleared up numerous injuries, and has allowed lifters to focus on lifting the largest weight possible on the snatch and clean and jerk. The technique has progressed to a point where biomechanical analysis is the next step needed to continue the progress of the sport. This would assist coaches in determining areas of focus for the programming and technical assistance with drills on more of an individual basis.

Phases of the Snatch and Clean and Jerk

In both events, the snatch and the clean and jerk, the barbell starts from the floor and is completed with the barbell in an overhead locked position, showing a moment of stability in this final position. The snatch is maneuvered to this final positon in one motion, usually to a squatted position and must stand erect for a successful lift. The second event in weightlifting, known as the clean and jerk is a two motion lift. The first motion, the clean, the lifter pulls the barbell from the ground to a front racked position on the shoulders. This is also caught in a squatted position, and the lifter must stand erect prior to the second motion. The second motion, the jerk, takes the barbell from the front racked position to the overhead final position in a driving motion (Stone et al., 2006).

Much of the factors influencing success in a lift can be narrowed down to different phases within the lift. In the snatch, the first phase is referred to as the first pull, and begins with the lifter breaking the barbell from the ground and continuing to pull until the beginning of the second knee extension. To understand at which point the second knee extension begins, there needs to be discussion on the mechanics of the knees during the pulling phase of the Snatch.

The lifters objective during the pull is to navigate the barbell around the knees, while having a minimal moment arm between the barbell and the lifters center of mass (COM). The technique that has been adopted by elite lifters is referred to the double-knee-bend (DKB) technique (Hydock, 2001). This technique is defined by the first extension phase of the lifters knee until the barbell is above the knee. At this point the knee angle is decreased approximately 20 percent during a knee flexion phase (Bartonietz, 1996). The primary purpose for this knee flexion is to reduce the moment arm of the barbell to the lifters COM. In some studies, this has been observed on average to decrease the moment arm by .04 m (Enoka, 1979).

Not only does the knee flexion reduce the moment arm of the pull, but simultaneously the trunk of the lifter has been observed to extend 38 degrees (Enoka, 1979). With a more vertical torso, this creates approximately a 70% reduction in hip extensor forces (Cholewicki, McGill, & Norman, 1991). Due to the force-velocity curve, this change in forces allows the lifter to then extend at the hip joint with much more velocity in the following phase of the pull (Wilkie, 1949). This is optimal for the lifter to use because it also allows for a stretch-reflex at the knee joint, as well as the knees being at an optimal angle to re-exert force. This optimal knee angle range to produce peak force has been found to be between 120 and 145 degrees at the knee joint (Enoka, 1979). The lifter resumes extension about the knee joint for the second time, following the knee flexion.

The moment the knee joint returns to extension, is the start of the second pull. The second pull is concluded at the instant of maximum vertical velocity of the barbell, when the athlete is in the fully extended top position. This normally occurs approximately .2 seconds prior to maximal barbell height (Garhammer, 2001). The second pull is characterized by the most powerful phase of the lift. This is largely due to the muscles surrounding the ankle, knee, and hip joints, being at ideal ranges in the length-tension curve to produce the most force, along with the increased velocity at the hip joint from the more vertical torso angle (Enoka, 1979).

The first and second pull is the traditional breakdown of the pulling phase in the United States, but there is some variation in literature worth discussing. In elite lifters, it has been observed that there are three peak vertical accelerations of the barbell throughout the pulling phase. These three accelerations were observed during the first knee extension, the knee flexion period, and the second knee extension (Isaka, Okada, & Funato, 1996). Since there is a significant event in each of the three phases of the knee, Isaka argues that each phase of the knee should be considered a separate phase of the pull. The first extension of the knee was defined as the first pull. The flexion of the knee during the pull is referred to as the transition, and the second knee extension is still considered the second pull. This better reflects the phases when dealing with barbell acceleration kinematics.

Also, research on GRF of the pull by Enoka (1979) reveals a similar trend of three defined periods during the pulling phase. The periods were defined by whether or not the GRF was larger or smaller than the mass of the system. The mass of the system is defined by the lifter and the barbell mass combined. There were two "weighted" phases, where GRF was greater than the systems mass, and one "unweighted" phase, where the GRF was less than the system's mass, observed during the pull (Enoka, 1979).

These phases coincide with the breakdown of Isaka's findings, but instead of looking at the knee angle to determine the start and end of a new phase, Enoka used instants where GRF was equal to the system's mass. The first weighted phase similarly follows Isaka's defined first pull. The unweighted phase coincided with Isaka's transition phase, and the second weighted phase coincides with Isaka's second pull phase. The GRF during the weighted phases produced 120-167% of the mass of the system. The GRF during the unweighted phase produced force, only 57-88% of the mass of the system (Enoka, 1979).

The key difference in Enoka's kinetic definition of the pulling phases compared to Isaka's kinematic definition, is the moment where each phase ends and begins, except for the start of the first pull. These slight variations are due how forces are generated from the ground and transferred through the body, to the barbell, often referred to as the kinetic chain. The GRF for a given event occurs prior to kinematic observation due to this transfer of forces (Lei, Liu et al., 2006). Lee, Huwang, and Tsuang (1995) observed these findings and further found that in the event of a maximal force being applied to the barbell, GRF reaches its maximum first, followed by peak angular velocity at the knee joint, and finally barbell velocity. This explains why Enoka found that the instants that the GRF was equal to the system's mass occurred slightly before the change in knee direction. Thus, the first pull ended slightly prior to the switch to knee flexion, the transition ended slightly prior to the second knee extension, and the end second pull occurred prior to the maximal velocity of the barbell (Enoka, 1979).

The moment after peak barbell velocity marks the beginning of the catch phase of the snatch. This is where the lifter drops under the barbell to "catch" the weight. Competition level lifters tend to drop as low as possible, usually in a deep squat position for greater efficiency in the lifts before they recover and stand erect (Gourgoulis et al., 2009). This technique allows lifters to successfully finish lifts without the need for excessive vertical barbell displacement. Elite lifters have been observed to only pull the barbell to 60% of the total height of the lifter (Baumann, Gross, Quade, Galbierz, & Schwirtz, 1988). Other findings have shown this height to be at the lower range with observations ranging from 62.1% in a 76 kg class lifter, up to 70.8% of a lifters height in 108 kg class (Isaka et al., 1996). There are anthropometric implications on the weight class of the lifter and the total vertical displacement needed to successfully snatch, but will touched upon in later subsections.

During the catch phase, the barbell begins accelerating toward the ground from its maximal vertical height due to gravity. The greater peak vertical velocity the barbell has at its maximum, allows the lifter more time to drop under the barbell without the barbell gaining too much velocity toward the ground for the lifter to catch. This factor is very important because in the rules, the Snatch is only counted successful if the arms remain locked-out in the overhead catch position. Any slight flexion of the elbow in the eccentric deceleration of the barbell in the catch is considered a failed lift in competition (International Weightlifting Federation [IWF] Rules, n.d.).

The catch phase is concluded at the point where the barbell has been decelerated to the first moment of positive vertical acceleration. It’s important to note that subsequent instants of negative vertical acceleration may occur due to the lifter attempting to “bounce” in the bottom catch positon to maximize passive elastic components in concert with the active muscle contraction, in order to squat up efficiently (Wilkie, 1949).

After the first moment of zero vertical velocity in the bottom catch position, the lifter then enters the final phase of the snatch, the recovery. The recovery phase is where the lifter squats the overhead barbell from the bottom position in the catch to a fully erect position. The lifter is allowed to move anywhere on the competition platform in order to regain stability overhead as long as the elbow joint remains locked-out (IWF Rules, n.d.). Although, taking a step during the recovery is an indicator of inefficiency. The lifter must also demonstrate a brief moment of stability to the judges in the erect overhead position in order to receive a “down signal” from the judges, allowing the lifter to drop the barbell.

The clean and jerk shares many phases to that of the snatch. The key difference between the snatch and clean and jerk is the grip width, and how the barbell is caught. The snatch features an ultra-wide grip in order optimize the moment arm of the barbell during the second pull, and to be able to successfully catch the barbell with less vertical displacement. Since the clean is caught in the front rack position, the optimal grip varies, but normally lies slightly wider than shoulder width. Clean grip varies between lifters depending on their strengths and weaknesses, such as a wider grip, like the snatch, is used by lifters with exceptional range of motion (ROM) in the shoulder and wrist joints to move the barbell slightly closer to the lifters COM at the point of triple extension. Lifters also alter the moment arm of the clean by having a slight bend in the arms during the pull. There is controversy in this technique because the arms are supposed to contribute primarily after triple extension, and most philosophies agree that higher peak forces can be exerted by the arms if there is minimal activation prior to this point (Stone et al., 2006).

The clean shares all the phases discussed above in the snatch, but the key difference is in the shoulder width grip. This allows the body to be more erect when navigating around the knee, but it also places the barbell much lower upon hip contact. Since the main objective in the first pull is still to navigate the knee joint with a minimal moment arm, the barbell maintains almost the same trajectory to that of the snatch, while the ankle, knee, and hip joints of the body will be more erect at the end of the first pull. In the second pull, the lower extremity joints follow the similar angles as the snatch, while the barbell reaches hip contact much lower than the snatch (DeWeese et al., 2012). Lifters with poor pulling mechanics often change their technique in the second pull, as discussed previously, to bring the hip contact closer to the lifters COM.

The catch phase for the clean begins after positive peak barbell velocity occurs and ends once the positive acceleration is noted in the bottom, catch position. Since the barbell is caught in the front rack position, the lifter does not need as much vertical displacement as the snatch, and can have more horizontal velocity due to more stability when the barbell is not balanced overhead. The recovery phase is the same between lifts, where the lifter stands erect from the bottom position.

While the snatch is complete after this phase, the lifter must still jerk the barbell overhead to complete the clean and jerk. The lifters take a moment while standing to regain their breath in order to maintain rigid positions in the jerk. There is a balance of time under tension and recovery that influences how long the lifter takes to regain their breath. Taking too much time to recover results in fatigue due to time under tension, while fatigue also occurs if no time is allowed between the clean and the jerk (Zatsiorky & Kraemer, 2006).

The lifter then enters the dip phase of the jerk. This phase is implemented to create momentum in the barbell while initiating a stretch-reflex. With the torso remaining vertical, the knees move into flexion until the body is a few inches lower than erect. The moment the lifter switches from knee flexion to knee extension, the lifter enters the drive phase of the jerk. The lifter drives the barbell vertically until triple extension, to produce maximal power into the barbell. The lifter continues pressing the barbell with the arms in order to force themselves under the barbell, amortizing the body in preparation for the large forces that will be required to catch the barbell (Zatsiorky & Kraemer, 2006).

The start of the catch phase begins after maximal positive vertical velocity of the barbell, and is continued until the barbell reaches zero vertical velocity in the bottom of the catch position (Stone et al., 2006). There is not a rule on foot placement for the jerk, as long as the overhead locked out arms do not bend at any point, similar to the snatch rule. Currently, the most popular foot position is the split stance, where the feet are split into a lunge position. Other variations include the power jerk, where the feet only gain width and the body catches the barbell in a quarter-squat position, or the squat jerk, where the feet once again gain width, but the lifter drops to a full depth squat. The obvious rationale for the squat jerk is the minimal vertical barbell displacement needed to successfully catch the barbell. Instead, the lifter needs exceptional ROM and stability in the shoulders to compensate for lack of vertical displacement (Garhammer, 1993). The jerk is complete after the jerk recovery phase, where the lifter stands fully erect with the barbell overhead, realigning the feet to a parallel shoulder width stance.

The phases of the Snatch allow the lift to be properly compartmentalized. This simplifies the lift into key objectives in each phase to produce optimal success. Due to differing philosophies among the top Weightlifting countries, different key events are chosen to value, reflecting the subtle changes in Weightlifting technique around the world. Success in Weightlifting, regardless of differences in philosophy, has been achieved by chunking the lifts into areas of greatest concern.

Technique

In order to have correct positioning at the end of the pulling phase, the first pull needs to remain rigid to be able to maintain the optimal kinetic chain for the latter part of the pull to be effective. The largest forces are observed in spinal loading and hip joint torque at liftoff due to the angle of the trunk, and the surrounding musculature being in an unfavorable range of motion to create the large forces needed. These shear forces created in the lumbar spine largely correlate to angle of the torso, weight of the upper body, and barbell load (Cholewicki et al., 1991).

A study by Gourgoulis (2009), specifically looks at Elite lifters and assesses various variables to figure out correlations to unsuccessful maximal effort lifts. The majority of variables tested in this study showed no significance in between successful and failed snatch attempts. “Regarding the trajectory of the barbell, no significant differences were observed between successful and unsuccessful lifts in the maximum height of the barbell or in the horizontal displacement of the barbell toward or away from the lifter, nor were any observed in the height of the barbell at the end of the first pull, the transition phase, and the second pull”.

Two significant differences were observed in this study, but only in the first pull of the lift. One correlation was the direction of forces that the lifter exerted into the barbell. To illustrate this, force vectors were calculated on small intervals throughout the first pull. The other significant finding was the vector of the acceleration vector from the center of pressure of the lifter’s feet. Gourgoulis used this vector to find an angle in reference to the vertical plane.

The first pull and second pull both bring a different objective to the Weightlifting movements. The first pull is a slower movement that produces the largest amount of force in the movement (Lee et al., 1995). Whereas, the second pull exhibits much greater velocities, thus producing the largest amount power in the movement. This shows that absolute strength is a main factor in the execution of the first pull in proper positions, and the element of mechanical power is the main factor that creates success in the second pull (Hadi, Akku, & Harbili, 2012).

With the recent change in the rules to allow the barbell to touch the lifter's body during the execution of the lift, lifters can minimize the moment arm, barbell to lifter COM separation, putting the barbell in an optimal position at the point where peak power occurs, during triple extension. Triple extension is defined as the simultaneous full extension of the hip, knee, and ankle joints. This event produces the most external power on the barbell (Kipp et al., 2013). In order for the Weightlifter to be able to produce maximal force into the barbell at the point of triple extension, one must be in a very specific position in relation to the hip, knee, and ankle joints at the start of the second pull. This position maximized the use of the hip joint due to the largest musculature surrounding that joint.

There are two typical barbell velocity curves observed during the pull phase. Elite lifters show one peak velocity, while more novice lifters usually show two peaks. The velocity curve with two peaks occurs before and after the deceleration from knee flexion in the transition phase. Deceleration of the barbell occurs regardless of skill if performing the DKB, but elite lifters are able to plateau the velocity of the barbell during knee flexion, resulting in one larger peak, as opposed to two smaller peaks (Baumann et al., 1988). This single peak in velocity is largely due to the tempo of the pull. The first pull must not be too fast, because the deceleration from the transition phase will be significantly larger, resulting in two separate velocity peaks (Bartonietz, 1996).

Peak velocity in the pull is directly correlated to the weight successfully lifted. In competition, larger loads lifted result in decreases maximal velocity, average velocity, and power output. Larger loads also increase the duration of the pull (Garhammer, 2001). At the practical level, some of the most important indicators for training intensity are the relationships between barbell displacement and time, and barbell velocity and time (Isaka et al., 1996). Bartonietz (1996) gave an example of a subject in his study, which can maximally lift 190 kg. In order to reach desired barbell height, the peak velocity needs to be at least 1.83 m/s to get the desired height of the barbell. In training, if the lifter wants to retain the ability to snatch 190 kg, but trains with lighter loads, the velocity must be greater to obtain the same intensity needed to lift 190 kg. If the lifter snatches 180 kg than the barbell peak velocity must be at least 1.93 m/s, and 170 kg lifted at 2.04 m/s (Bartonietz, 1996).

Even after the barbell reaches the desired height after the pull, the lifter is taught to continue to actively pull through the barbell to keep it tracking over the lifter's COM, and to force the lifter under the barbell quicker than gravity alone. It is necessary for lifters to be actively pulling throughout the lift, with the arms, in order to make sure the barbell ends over-top the lifters COM. "Elementary physics mandates that the mass of the barbell will move towards the center of mass of the body supporting it, to a point where the system COM (barbell and human) is supported over a point midway between its most anterior and posterior points of support" (Hancock et al., 2012).

In comparison to novice lifters, elite lifters all share a much more similar pulling style regardless of weight category, gender, and age (Stone et al., 1998). This is due to the optimal bar path that is able to be better adhered to, and more consistently by elite lifters. This added validity and reliability is beneficial to assessing the variables that have previously been identified that correlate to the failure of the lift. The proper intensities to observe these variables must be considered as well because elite lifters are rarely unsuccessful with attempts lower than 80%. By choosing an elite level competition for data collection, research is able to better understand the subtle technical trends and differences in optimal technique, depending on asymmetries and anthropometrics.

Anthropometry

Currently, there are 8 weight classes that range in weight from 56 kg to 105+ kg class for the men and 7 weight classes that range from 48 kg to 75+ kg class for the women. The average height in the 2012 London Olympic Games for the 56 kg class was 5’2”, while the 105+ kg class had an average height of 6’1” (Winter, 2012a). The same trend follows for the women’s height. Height and limb length has been closely examined by coaches and researchers when deciding on the ideal candidate to develop in training.

Ho et al. (2011), conducted a case study observing a novice Weightlifter with a height of 5’7” and a weight of 74.8 kg. With his body size there was a correlation found of the anterior pelvic tilt greater than 17.6 degrees, and the hip joint less than 89.6 degrees at liftoff maximized the success rate of the subject. Other studies have found that shorter lifters at the elite level begin their first pull from a knee angle of 80 degrees, and the taller lifters first pull began with a knee angle of 47 degrees (Bartonietz, 1996).

Instead of setting a specific angle in the knees or hips to obtain, a more general coaching cue has been developed to optimize starting position. The cue is to align the lifter's mid scapula, the barbell, and the ball of the foot in a vertical, straight line (Figure 1). It is a common misconception to align the acromioclavicular joint (shoulder) vertically over the barbell and ball of foot, but since the barbell is far from the lifters center of mass, one needs to lean slightly further over the barbell to create the least horizontal displacement (Hancock et al., 2012).

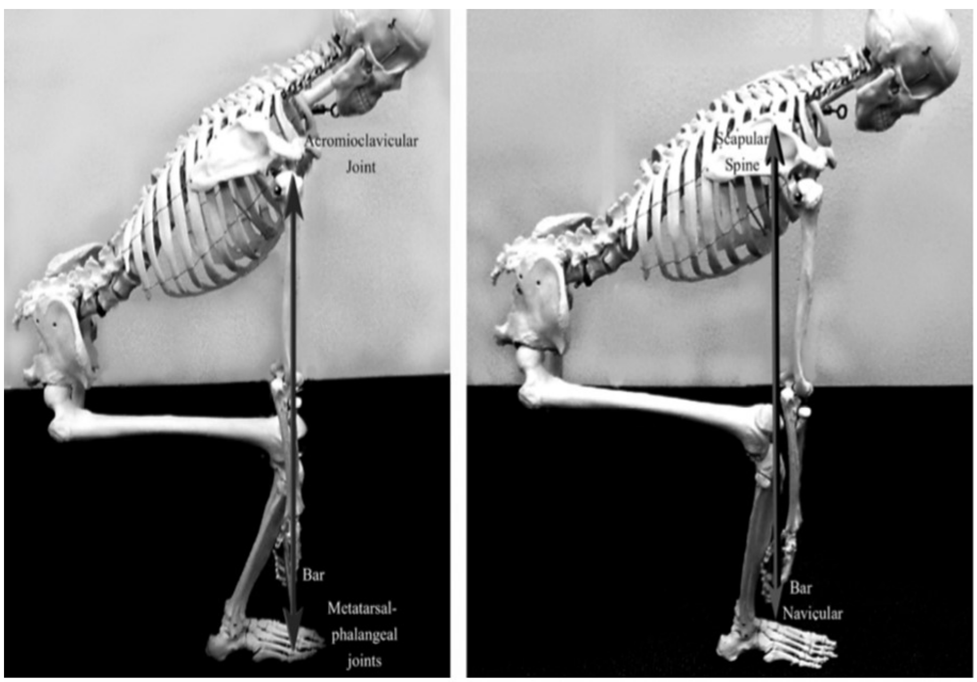

FIGURE 1. Weightlifting setup. Pictured on the left is the misconception of the proper setup, whereas the picture on the right shows the correction for the proper setup (Hancock et al., 2012).

There are many lifters that are successful in the sport of Weightlifting that cannot obtain these angles on their starting position, which is often due to a lack of range of motion (ROM) or asymmetries in the body. Some solutions are easier than others, for example China's former World Champion Lu Xiaojun, has worn a modified weightlifting shoe to have an even more exaggerated heel than normal in order to overcome his lack of ROM in his ankles (Winter, 2012b). Other problems in ROM and asymmetries may not be as easy to correct, but lifters make adjustments in technique that are unique to that individual.

Many of the top Weightlifting countries recruit at a young age with anthropometric measurements being a key, along with hormonal, mental, and general strength tests (Fair, 1987). The ideal body type for a Senior Weightlifter is a generally short and stocky stature, long arms, short legs, and a long torso. Specifically, in the legs, a long shank and short thigh has been correlated to rank in international level competition (Musser et al., 2014). The anthropometrics of an ideal body for pulling in powerlifting coincides with the same body type: short legs, long arms, and a long torso. These anthropometrics also coincide with the ideal body type to reduce shear forces in the lumbar spine (Cholewicki et al., 1991).

The lower back in Weightlifting seems to be a reoccurring area of focus. With the torso in such a horizontal starting position, large forces are needed from erector spinae in order to maintain lordosis in the lower back during the first pull. The body's default, if erectors cannot provide enough force, is to shorten the lever of the torso by putting the back into hyperflexion (Cholewicki et al., 1991). Not only is hyperflexion of the spine dangerous to the lifter's health, but the pull's efficiency will be compromised due to inefficiency in the kinetic chain. Forces in the barbell at the first knee extension will not experience much inefficiency and possibly increase forces due to the shorter lever at the torso due to the hip joint remaining relatively static. The second pull would experience the greatest loss in energy transfer with a hyperflexed torso due to the dominance of the hip joint in this phase of the pull. So, by reducing the load on the lumbar spine with ideal anthropometrics, the lifter is able to handle greater load on the barbell without compromising the kinetic chain.

Not only does segment length allow lifters to reduce loads in the lumbar spine, but the optimal appendage lengths discussed, are also correlated to smaller horizontal displacement, specifically in the second pull (Musser et al., 2014). Minimizing horizontal displacement is ideal for lifters because horizontal acceleration occurring at the barbell, results in force transmission to the barbell away from the desired vertical direction (Isaka et al., 1996).

Lighter weight class's peak barbell height have been observed to only need to reach 72% of the height of the heavier weight classes barbell height (Bartonietz, 1996). With these differences in peak barbell height, there are implications on necessary barbell peak velocities as well. Using the same example, the lighter lifter, weighing 52 kg, only needed apply a maximal velocity of 1.5-1.6 m/s to the barbell in maximal effort attempts. Whereas the superheavyweight lifter required 1.9-2.0 m/s peak barbell velocity to have success with the same intensity of lifts. These differing barbell heights come from the lowest position the lifter can attain in the catch with the arms locked-out over the COM.

As discussed earlier, there is a trend of heavier weight classes having a larger average height and arm length than lighter weight classes. Taller athletes also generally lack the range of motion of their smaller counterparts (Garhammer, 1985). These two factors increase the heavier weight class's catch position height.

Along with bottom position, the turnover is often referred to as a point of emphasis in the catch. This refers to how quick the lifter can move from full extension at the top of the lift to the catch position in the bottom of the lift. The faster the turnover is achieved, the larger the loads can be lifted. This is because lifters do not catch the barbell at maximum height, instead elite lifters have been found to catch the barbell at 60-70% of the peak barbell height, also known as vertical displacement in the catch. The vertical displacement in the catch phase is defined as the distance between the peak height of the barbell and the lowest position of the barbell in the bottom of the catch. In elite lifters, this vertical displacement ranged from 10.1-24.3 cm, with a trend of larger weight classes having more vertical displacement (Isaka et al., 1996). Once again, these larger weight classes possess taller athletes that have more distance to cover in the turnover.

Even though greater vertical displacement allows the lifter more time to situate under the barbell, the extra time comes at a cost. For example, if a 180 kg barbell is free falling 10 cm without initial velocity than the final velocity would be 1.4 m/s. Whereas, the barbell falling 24 cm would have a velocity of 2.17 m/s. What seems to be a better depiction of the impact is the kinetic energy that is created with this extra velocity. A barbell free falling only 10 cm would result with the barbell having 176.39 J of kinetic energy, and by increasing this free fall distance by almost 150% would result in the barbell having 423.8 J of kinetic energy.

Trends seem to emerge in elite lifters, largely due to the reliability of the recruiting process that has been refined by countries around the world. Technical cues are often given to the lifters in order to align the levers of their body properly, but outside of the elite level of Weightlifting, anthropometrics range much broader. In these circumstances joint angles are no longer relevant cues. Instead, visualization cues, such as the cue of mid-scapula, barbell, and ball of foot alignment on liftoff, should be developed in order to apply to a wider range of the Weightlifting world.

Trajectory

The most efficient path between two points is known to be a straight line. This maximizes the distance traveled in the desired direction. In Weightlifting, the same basis holds true in relation to barbell path. The problem gets more complex when the barbell needs to be balanced over the lifters COM at the end of the lift. Lifters begin with the barbell in front of their COM in order to navigate around the body, but end with the barbell directly overtop their COM.

The lifter first addresses this problem by aligning the barbell, balls of the feet, and mid-scapula in the vertical plane, allowing the lifter to initially pull the barbell gradually back toward the lifter's COM (Bartonietz, 1996). These horizontal displacements are necessary due to the shortened moment arm at triple extension and other factors previously discussed. The acceleration angle of the barbell during the first pull has been observed in elite Asian Weightlifters at 85 degrees in reference to the horizontal plane (Isaka et al., 1996).

The barbell then anteriorly displaces due to hip contact from the lifter's COM at the point of triple extension (Garhammer, 2001). This allows the lifter to apply full potential of the hip joint activation to the barbell, creating an illogical acceleration of the barbell away from the lifter. The average acceleration angle observed at this phase in the same elite Asian lifters was 140 degrees in reference to the horizontal plane. This anterior acceleration of the barbell is countered by the body pulling back and under the barbell in the turnover of the catch (Isaka et al., 1996).

During the catch, the barbell is still actively being pulled. As touched on earlier, actively pulling during the catch increases the speed of the turnover, but the active pull also is responsible for the final loop seen in barbell trajectory (Musser et al., 2014). This final phase in the barbell trajectory pulls the barbell over the lifters COM. This barbell trajectory is most efficient due to the lowest cost of actuating torques, the implementation of a stretch-reflex in the DKB, and maximizing forces in the vertical direction (Nejadian, Rostami, Arshi, & Naghash, 2009).

With all the horizontal displacement involved, it is common for elite lifters to jump backward into the catch. The average displacement of elite lifters is 1cm displacement, forward or backward, from the lifter's original foot position (Gourgoulis et al., 2009). Weightlifting coaches are much more lenient to a lifter that has negative displacement of the feet as opposed to positive feet displacement (Hori et al., 2005).

Vorobyev has considered negative displacement to be a fault in technique upon original discovery, due to the belief that the barbell should closely follow and cross the vertical reference plane (VRP) to reduce horizontal displacement (Baumann et al., 1988). The VRP is used in reference to barbell trajectory, and is created using the location of the barbell prior to liftoff. Instead of the barbell crossing the VRP, much evidence supports the best trajectory of the barbell stays posterior of the VRP.

Although, this is not the only type of trajectory seen in international caliber competition. For referencing purposes, the pull with the trajectory entirely posterior to the VRP will be considered a “type 2” pull. Prior to the acceptance of the type 2 pull, a more vertical bar path was imagined to be the most efficient. This barbell path begins with the same posterior displacement as the type 2 pull, but the second pull displacement crosses the VRP (Musser et al., 2014). This makes the barbell path look much more linear, and does in fact result in less displacement of the feet than the type 2 pull. For referencing purposes, this traditional trajectory will be referred to as a “type 1” pull.

Finally, there is a third barbell trajectory that has been observed in international competition. This pulling style is the most unique, starting with anterior barbell displacement in the first pull. During the DKB the barbell moves in the posterior direction crossing the VRP until the point of contact in the second pull. The barbell, now moving anterior again, crosses the VRP until the final loop over the lifter’s COM (Musser et al., 2014). This style also results in minimal displacement of the feet. For referencing purposes this barbell trajectory will be referred to as a “type 3” pull (Figure 2).

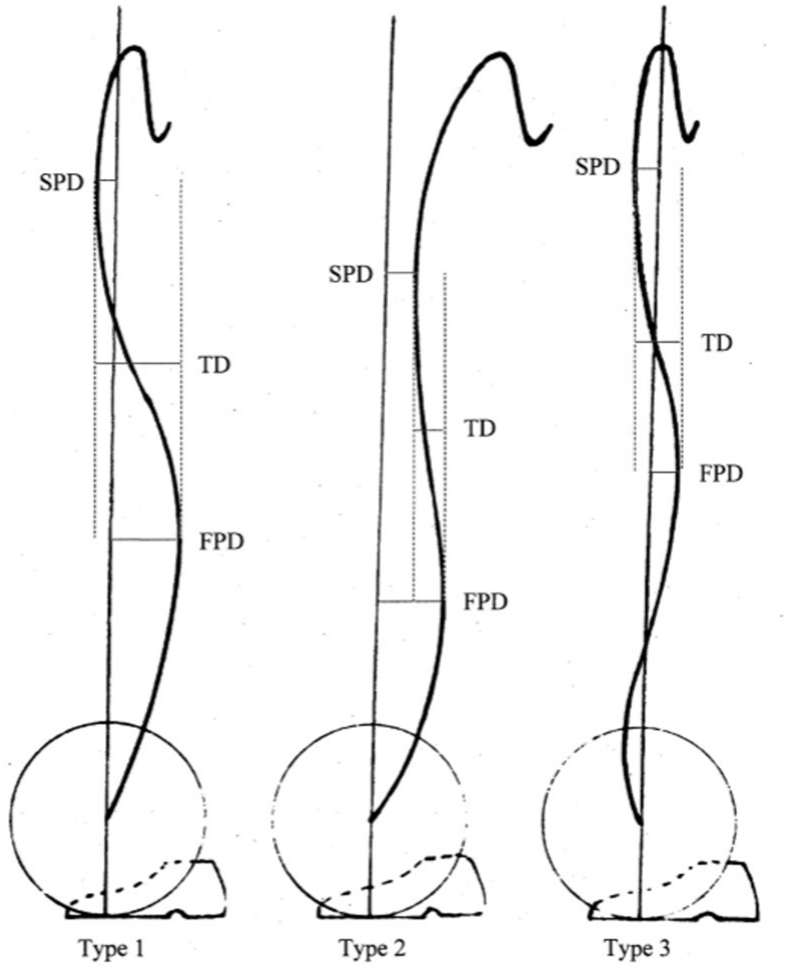

FIGURE 2. Common Bar Path Styles (Musser et al., 2014).

A popular variable to study in relation to barbell trajectory is the total amount of horizontal displacement (TD). This is the modulus sum is of the furthest posterior position of the barbell, occurring at first pull, added to the barbells furthest point of anterior barbell displacement, occurring in the second pull. The modulus distance is in reference to the VRP. The average TD found in elite lifters is approximately 10 cm (Isaka et al., 1996). Within elite competitions, there are ‘A’ and ‘B’ sessions that separate the best from the best. Even within this tight grouping of skilled lifters there has been significant correlation to lifters in the ‘A’ session having less TD than lifters in the

‘B’ session (Baumann et al., 1988). A separate study agrees with the correlation between TD and rank in elite competition (Musser et al., 2014).

Also, within the ‘A’ and ‘B’ sessions of elite competition another correlation commonly found that lifters in the ‘A’ sessions have a negative foot displacement as seen in type 2 trajectories. This is supported by Musser’s (2014) work by comparing barbell trajectory type to the rank and medalist recipients. Type 2 female lifters in the 2009 Pan American Weightlifting competition were awarded 72.2% of the medals, type 1 was awarded 27.8% of the medals, and type 3 lifters did not medal at all (Musser et al., 2014). Interestingly found, was that only type 2 lifters were awarded gold medals.

There also have been correlations found between barbell trajectory and torso length. Within elite competition, many of the lifters were the product of recruitment at a young age. Therefore, the lifters share similar anthropometric measurements, and yet different barbell trajectories are still observed. Non-anthropometric variables observed in regards to rank were: experience, front squat max, and back squat max (Musser et al., 2014). These variables allude to the ideal trajectory being a factor of relative strength level, and the amount of practice the lifter devoted toward eliminating of horizontal barbell displacement.

While type 2 trajectories were observed in every weight class, type 1 and 3 trajectories were only observed in specific weight classes. Type 1 trajectories were exclusively observed in lighter weight classes in the 2009 Women’s Pan American Weightlifting Competition, at 48, 58, and 63 kg classes. While type 3 trajectories primarily occurred in the heaviest weight classes, 75 kg (Musser et al., 2014).

At lighter weight classes, elite lifters have been known to lift 2.5 times their bodyweight, whereas the heaviest snatch ever in competition was less than two times the superheavyweight's body weight (Stone et al., 2006). Since the lighter weight classes are lifter a higher percentage of their weight, the horizontal accelerations to manipulate the barbell in turn need to be relatively larger as well. With large horizontal accelerations come larger horizontal displacements of the lifter and barbell.

Also, when comparing TD of lifters first attempts against their third attempts, lighter to heavier respectively, more displacement is observed in the first attempts (Garhammer, 2001). The displacement occurring in the first attempts are still able to be successful due to the load being lighter and the lifter being strong enough to account for a larger margin of error in technique. The barbell at lighter attempts also has been observed to produce more power than heavier attempts. This is largely due to the increased velocities and shorter durations of the pull phase at lighter attempts (Garhammer, 2001).

With the adaptation in the rules to allow hip contact, a new ideal trajectory needed to be developed. The addition of hip contact complicated the ideal trajectory of the barbell that lifters should adopt, largely due to the application of better moment arms during the pull. The cost of a better moment arm was the deflection of the barbell, away from the lifter, at hip contact. Horizontal barbell displacement is a primary factor that needs to be monitored and minimized for success when implementing the hip contact. There calls for further research to assess how horizontal barbell displacement changes in unsuccessful attempts.

Conclusion

Over the past 150 years of this sport's existence, it has been refining techniques and rules to optimize the amount of weight lifted overhead, along with doing so in the safest way possible. The modern day techniques have been segmented into multiple phases to assist researchers in assessing data. By chunking the lift into pieces it also allows the lifter to focus on improving specific phases, including the variable of barbell path. This allows research to better understand how anthropometric differences influence these technical variables. Some research has narrowed down possible variables in unsuccessful attempts, mainly within the first pull, that requires further attention. In order for the sport to continue to grow, there needs to be more refined technical cues that apply, not only to the elite lifters, but also to a much broader spectrum of the Weightlifting community.

CHAPTER III

METHODOLOGY

The purpose of this study was to determine if kinematic differences existed between successful and unsuccessful attempts at the same loads by the same lifters. This information is needed in order to develop a better understanding of proper pull angle for the population, along with the average margin of error one can allow to still successfully complete the lift.

Research Design

This is a descriptive based study that determined if kinematic differences existed between successful and unsuccessful snatch attempts. Subjects were filmed in a competition setting. These parameters were able to be met through the data collection of a National level Weightlifting competition, and through statistical analysis determining variables that significantly differ between the two attempts. For each subject, a successful attempt was compared to an unsuccessful attempt at the same load. Most variables identified from the data observed horizontal displacements of the barbell in each phase of the pull, along with how these displacements compared to the location of the lifter's COM.

Variable Definitions

DFP (m)- Peak horizontal displacement of the barbell from its starting position in the first pull.

DSP (m)- Peak horizontal displacement of the barbell from its starting position in the second pull.

D_{tot} (m)- The difference in peak horizontal displacement between the first and second pull.

H_{peak} (m)- Peak height of the barbell.

H_{catch} (m)- Height of the barbell at the catch.

V_{hor} (m/s)- Horizontal velocity of the barbell at peak height.

θ_{peak} (degrees)- The angle between the vector from the body COM to the barbell in reference to the vertical direction at the peak barbell height.

θ_{catch} (degree)- The angle between the vector from the body COM to the barbell in reference to the vertical direction at the catch.

Loop (m)- The horizontal distance from the barbell during the catch to a point earlier in the lift of equal barbell height.

Drop (m)- The vertical distance between the peak barbell height and the height of the barbell at the catch.

SEP_{pk} (m)- The horizontal distance between the body COM and the barbell at peak barbell height.

SEP_{ctch} (m)- The horizontal distance between the body COM and the barbell at the catch.

θ_{Shldpk} (degrees)- The angle between the vector from the shoulder joint to the barbell COM in reference to the vertical direction at peak barbell height.

$\theta_{ShldCtch}$ (degrees)- The angle between the vector from the shoulder joint to the barbell COM in reference to the vertical direction at the catch.

$\theta_{shldDiff}$ (degrees)- The change in shoulder angle from the peak height to the catch.

Research Participants

The six participants in this study were National level Weightlifters observed at a high level US Weightlifting competition. The session used in data collection was the female 58 kg A-session. Each lifter receives three Snatch attempts in competition. The lifter qualified for this study if she missed an attempt, and then successfully lifts the same load in a subsequent attempt. With National level competitions, each session is usually limited to no more than 20 participants. This study was IRB exempt thanks to the video being collected at a publicly-held contest at which there was no expectation of privacy.

Instrumentation

The instrumentation needed for collection was two high-definition (1080p) video cameras (JVC GC-PX1, Victor Corporation, Tokyo, Japan), recording at 60 Hz, and set at various angles to the competition platform (Figure 3). A 3-D calibration device was used to calibrate distances from each camera and its orientation to the platform. While the calibration device was in the center of the platform, three markers were placed on the three visible corners of the platform, from the video camera's perspective. Once data was collected it was digitized with the use of Maxtraq (Maxtraq, Innovision Systems Inc., Columbiaville, MI, USA). The video files from each camera angle were synchronized, and custom MATLAB programs (MatLab, The Mathworks, Inc, Natick, MA, USA) were used to collect 3D data from the video files.

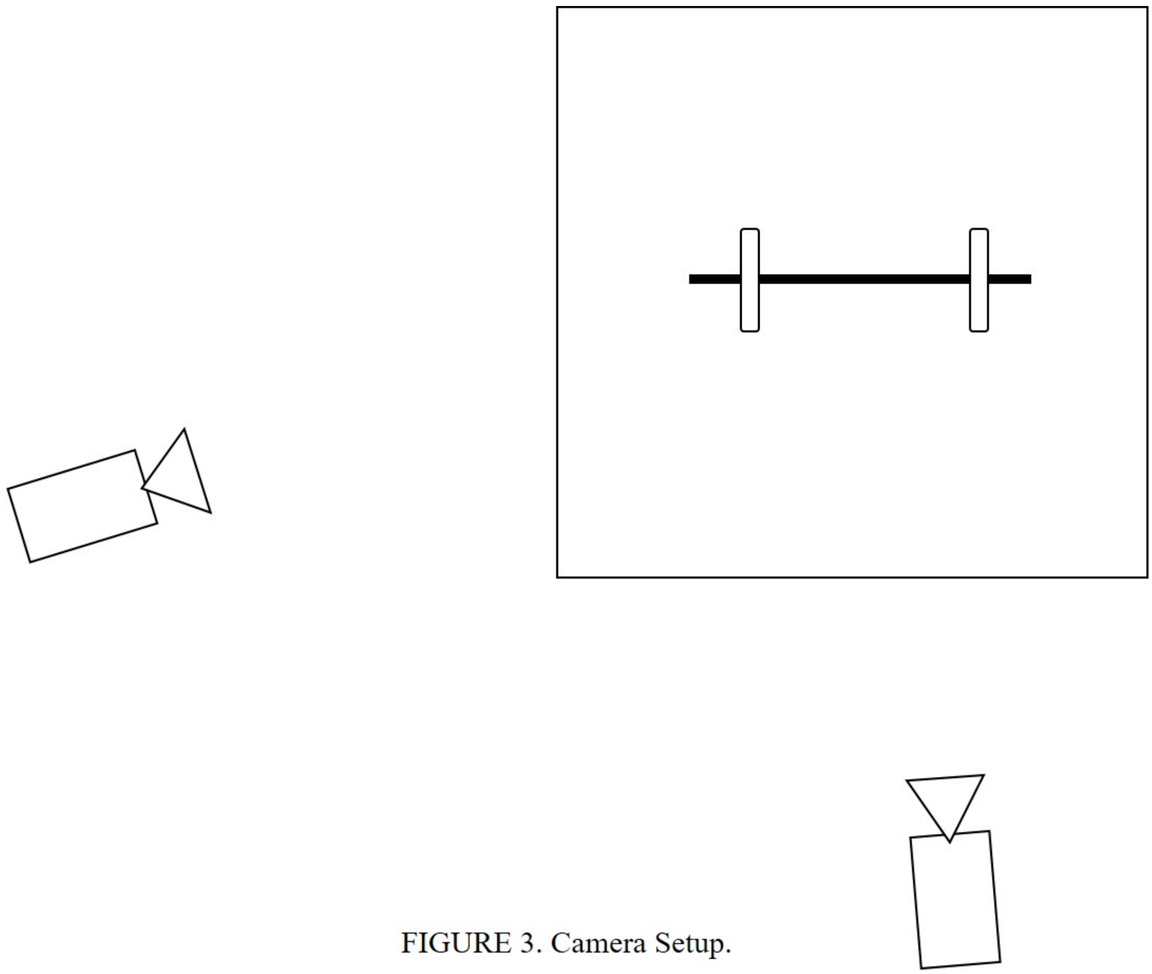

FIGURE 3. Camera Setup.

Procedures for Collecting Data

The female 58 kg A-session from the 2015 American Open was observed in this investigation. The competition took place in Reno, NV in a conference room of a hotel. All subjects wore a USAW sanctioned Weightlifting singlet. Each subject attempted three maximal-effort snatches on an 8’x8’ competition platform.

Each trial was videotaped simultaneously with two high-definition (1080p) video cameras (JVC GC-PX1, Victor Corporation, Tokyo, Japan), recording at 60 Hz. These cameras were placed close to 90 degrees. The cameras also recorded a video of the calibration device and centroids on the platform. This was filmed prior to the introduction of the athletes for that given session.

Subjects were then picked from the individuals that had originally missed a weight at load, and succeeded in their next attempt at the same load. Those six subjects' video files were downloaded on to a PC (Lenovo) computer. The locations of the barbell and of 21 body landmarks (vertex, gonion, suprasternale, right and left shoulders, elbows, wrists, third knuckles, hips, knees, ankles, heels, and toes) were manually digitized in every image captured by the two video cameras for each trial, using Maxtraq software.

Data Collection

The JVC GC-PX1 cameras use a rolling shutter. This exposes each frame progressively from top to bottom. Because of this, landmarks that appear in lower positions in a video image were exposed later than landmarks that appear nearer the top of the video image (Dapena, 2009). To solve this problem, the time assigned to a given point in a frame was adjusted to account for the additional time dependent on vertical location. This also took into account the brief duration between successive frames where an image has yet to be written

Due to a lack of synchronization of frames between cameras, events captured have been misaligned on different frames of the camera or in the previously discussed period of time between frames. Synchronization of cameras was established through the average difference at the point of visual events in the trial. The "events" used were the instants at which the barbell had broken from the floor, or the moments when the subject's feet had left and returned to the platform. A straight line with slope = 1 was fitted through the points by linear regression to calculate the synchronization between the frames of the two cameras.

Due to rolling shutter corrections, each point had a slightly different time scale, even though all points were digitized in the same frame. Quintic spline functions (Woltring, 1986) were fitted with no smoothing to the digitized coordinate-time data from each camera. Values were interpolated from the quantic spline functions of the two cameras for instants intermediate between frames and which did correspond in time ("output frames"). To facilitate comparisons between trials, the time t = 10.000 s was arbitrarily assigned to the instant of their first foot returning to the platform, and the interpolated values were computed for instants separated by intervals of .02 seconds.

The Direct Linear Transformation (DLT) method of videography (Abdel-Aziz & Karara, 1971) was used to calculate the 3D coordinates of the barbell and of the body landmarks for each output frame in terms of the global reference frame R_0. R_0 was a right-handed, orthogonal reference frame with rear-left corner of the platform as seen from the lifter's perspective. Its axes were defined by vectors $\mathbf{X_0}$, $\mathbf{Y_0}$, and $\mathbf{Z_0}$. $\mathbf{X_0}$ was horizontal, and directed along rear-left corner of the platform as seen from the lifter's perspective; $\mathbf{Z_0}$ was vertical and pointed upward; $\mathbf{Y_0}$ was perpendicular to both $\mathbf{X_0}$ and $\mathbf{Z_0}$, pointing forward toward the audience (Figure 4). The coordinates of two additional trunk landmarks, omphalion and xyphion, were estimated from the coordinates of the supersternale, shoulders, hips, and knees following a model described by Dapena (1993).

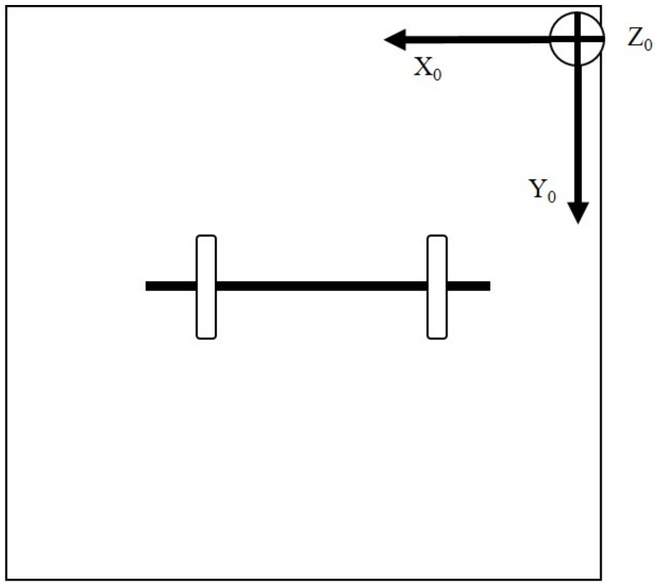

FIGURE 4. Orthogonal Reference Frame Setup

Quintic spline functions were fitted to the coordinates of the trial of each landmark using a smoothing factor that corresponded approximately to a digitial filter with a cutoff value of 6 Hz. These spline functions were used to calculate smoothed time-dependent 3D locations, velocities and accelerations for all landmarks.

Each subject was modeled as a sixteen-segment system, with the barbell acting as a seventeenth segment. The locations, displacements, and angles of the centers of mass of the body segments, of the barbell, and of the barbell-plus-lifter system, were calculated using procedures described by Dapena (1978, 1986).

With use of MATLAB first pull displacement was calculated by identifying the maximal horizontal displacement, whether it be a local maxima or minima, depending on barbell trajectory type. This same measurement was calculated for the second pull, and the total displacement was calculated by the difference in the greatest local maxima and the greatest local minima in the barbell trajectory. MATLAB used the barbell COM **Y-**

coordinates to find local maxima and minima in relation to the VRP. Resultant angle of the first pull was found by taking the derivative of position to yield velocity. Velocity was then derived to yield acceleration. The first pull was identified by the knee flexion by use of shank and thigh vector locations. A few variables regarding the angle between the lifter and barbell COM were found at both peak barbell height and at the catch. The VRF was always used as the other vector when finding angles (Figure 5).

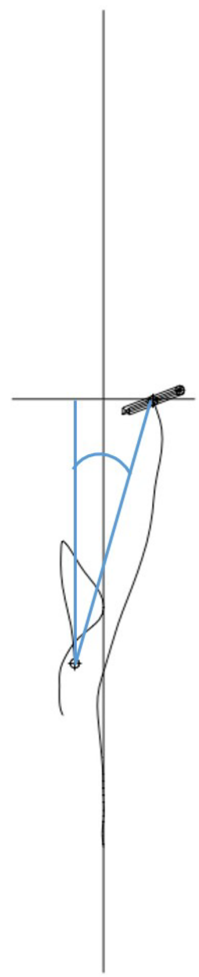

FIGURE 5. $\theta_{peak.}$ The angle between the VRF and the vector between barbell and lifter COM at peak barbell height. Where the horizontal reference line represents peak height of the barbell.

At the catch, a few other variables were assessed looking into the differences occurring between peak height and the catch. Both vertical and horizontal displacements were found and named drop and loop, respectively. While drop was measured from peak height to catch, loop was measured by the width between the catch and the point in the barbell path where it is the same height as the catch (Figure 6).

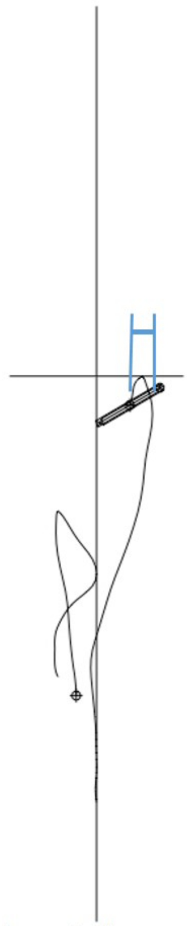

FIGURE 6. Loop. Horizontal distance from the barbell during the catch to a point earlier in the lift of equal barbell height. The horizontal reference line illustrates peak height, while the vertical reference line illustrates where the barbell began from the floor

Data Analysis

Paired sample T-test was used to determine if differences existed in the horizontal displacement and the velocity variables. Bonferroni paired T-test was used as a Post Hoc analysis. The alpha level was set at .05.

CHAPTER IV

RESULTS

Descriptive statistics (mean ± SD) of all variables separated by successful and unsuccessful attempts can be found in Table 1. The results of the paired samples t-tests are also located in Table 1.

Table 1.

Descriptive statistics and paired samples t-test results (n=6).

	Successful Attempt		Unsuccessful Attempt			
Variable	Mean	SD	Mean	SD	t	p
DFP (m)	-0.12	0.03	-0.12	0.02	0.0	1.0
DSP (m)	0.065	0.04	0.06	0.05	0.3	.778
D_{tot} (m)	0.08	0.03	0.07	0.05	0.28	.794
H_{peak} (m)	1.21	0.03	1.21	0.05	0.01	.99
H_{catch} (m)	1.16	0.03	1.12	0.03	2.0	.107
V_{hor} (m/s)	-0.24	0.06	-0.19	0.06	-1.53	.186
θ_{peak} (deg)	15.8	1.5	19.9	3.0	-3.74	.014*
θ_{catch} (deg)	9.7	1.4	11.3	2.3	-1.26	.263
Loop (m)	0.06	0.02	0.05	0.03	1.73	.143
Drop (m)	0.05	0.03	0.09	0.04	-1.56	.181
SEP_{pk} (m)	0.16	0.01	0.19	0.02	-3.4	.019*
SEP_{ctch} (m)	0.10	0.02	0.12	0.03	-0.99	.369
θ_{Shldpk} (deg)	26.2	12.6	38.1	14.1	-2.52	.053
$\theta_{ShldCtch}$ (deg)	5.6	2.8	6.8	5.1	-0.57	.594
$\theta_{shldDiff}$ (deg)	20.7	12.6	31.3	12.8	-3.34	.02*

*Indicates a significant difference between the two attempts.

CHAPTER V

DISCUSSION

The purpose of this study was to observe kinematic differences between successful and unsuccessful attempts at the same loads by the same lifters. This information is needed in order to develop a better understanding of proper pull angle for the Weightlifting population, along with the average margin of error one can have and still successfully complete the lift. In this study, peak barbell height was similar between failed and successful attempts indicating similar muscular efforts were created regardless of success. Instead, it is believed that technical differences were responsible for the failure. Since the goal is to bring the barbell over the lifter's COM, horizontal differences may be responsible for success, specific to the lifter and/or barbell.

There were multiple differences found at the peak barbell height of the Snatch. θ_{peak} was significantly more vertical in the successful attempts, showing that at the time of barbell peak, the lifter was further underneath the barbell than in missed attempts. Not only was the lifter not as far under the barbell in unsuccessful attempts, but the horizontal distance between the lifter and barbell COM was significantly bigger. These variables pose problems to the success of the lift because the lifter needs to move further underneath and reduce horizontal distance in a small amount of time.

The sooner the lifter is able to get into the proper catch position, the better the lifter is at decelerating the free-falling barbell. Another variable similar to θ_{peak} was found to be significantly different was $\theta_{shldDiff}$. In this segment of time, the shoulder joint only had to move 20 degrees from peak to catch in successful attempts, whereas the shoulder moved 31 degrees in failed attempts. With an additional 11 degrees of movement at the shoulder joint in unsuccessful attempts, the lifter faces the challenge of closing a larger distance between their COM and barbell, while gravity is speeding up the barbell.

Trending, but not significant, the barbell looped more in successful attempts because of greater negative horizontal barbell velocity at the peak barbell height. This is advantageous to the lifter because at the point of hip contact in the second pull, the barbell receives a positive acceleration away from the lifter and needs a negative barbell acceleration to make the barbell track back toward the lifter’s COM. If the barbell instead falls more vertically after the positive acceleration, the lifter is forced to displace their body more. Interestingly, there was no difference in how far the lifter COM moved in order to catch the barbell, even though as a whole, the lifters’ COM did not consistently displace forward or backward. As long as the barbell had a greater negative velocity, tracking back toward the lifter’s COM, the lifter had an easier time decelerating the load.

Another pattern that emerged was the drop of the barbell from peak height to catch height. The lifters caught the barbell 3 cm higher in successful attempts eluding to the turnover either being performed sooner or in less time than the failed attempts. Speed in the turnover is advantageous to the lifter because the lifter is able to catch the barbell closer to the peak height, which has no vertical velocity. Due to the acceleration of gravity, the barbell gets more difficult to catch the further the barbell has fallen.

The utilization of momentum in Weightlifting is the key that separates the elite from novice weightlifters. Therefore, novice weightlifters need to pull the barbell to a higher percentage of their total height to adjust for the lack of speed and accuracy in the turnover. Even though the lifters in this study were in the best session at a National level competition for their weight class, they still would be considered novice in comparison to the best International level lifters. These lifters showed consistency with the strength required to pull the barbell to a maximal height, but lacked the consistency in the turnover and strength in the upper body during the catch to account for the inefficient deviations in their barbell paths. Additionally, the participants in this study were female, and in comparison to male lifters, females do not attain peak forces as high as males in the same weight class. Males also tend to have greater upper body development, which may influence the margin of error one could have at the point of the catch.

Future research should examine the significant variables found in this study in correlation to displacements in the pull. This, along with body position, such as the back angle, at the end of the first pull may also reveal the origin of the errors in the barbell path. Practical research should look to create different exercises that would primarily focus on speed and accuracy of both barbell path and turnover. Drills could consist of the utilization of targets for the barbell to touch in order to produce a more consistent pull. The use of accommodative resistance, such as bands or chains, may be used effectively to accomplish these training goals for turnover as well.

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