The Effects of Anthropometrics on the Start Position of the Snatch: Implications for Bar Path Kinematics.

by

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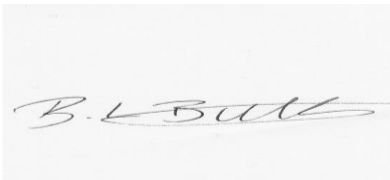

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Abstract

INTRODUCTION: Optimising an individual lifter's hip height at the start position (SP) of the Snatch lift (SN) has been identified as a key factor in determining a successful lift. Whilst it has been indicated that individual anthropometrics affect Olympic lifting mechanics and technique, anthropometrics has also been shown to affect the direction of the bar from the SP to the end of the FP. Considering that it has become widely accepted that a lifters SP is influenced by their height, body mass, somatotype and body proportions, the aim of this research is to provide insight into the relationship between anthropometric characteristics and adopted SP and how this affects kinetic and kinematic variables at the SP. **METHODS:** 20 experienced male weightlifters performed three single lifts at 85% of their most recent one repetition maximum (1RM). Kinetic and kinematic data of the barbell and lifter were collected during each trial using Qualisys Track Manager before being exported into visual 3D where the outcome measures and anthropometric data were derived. The Outcome measures were Ground Reaction Force Vector Angle (GRF°) at the SP, Absolute Hip Height at the SP relative to the floor and Maximum Horizontal Barbell Displacement (MHBD) from the SP to the FP. The anthropometric characteristics analysed were: absolute body segment lengths, absolute limb length ratios and body segment lengths normalised to standing height. A stepwise regression analysis was then performed to see whether anthropometric variables predicted each outcome measure. **RESULTS:** Absolute Femur length (r^2=0.34, $p<0.01$) and shank to femur ratio (r^2=0.20, $p=0.05$) were found to be significant predictors of absolute hip height at the SP of the SN. Relative femur length (r^2=0.45, $p<0.01$), relative trunk length (r^2=0.69, $p<0.01$) and shank to femur ratio (r^2=0.77, $p<0.05$) were found to be significant predictors of the GRF° at the SP of the SN. No anthropometric variables were found to be significant predictors of MHBD. **CONCLUSION:** Based on these results it can be concluded that a lifters femur length, shank to femur ratio and relative trunk length are the most important anthropometric parameters to consider when optimising an individual's SP for the SN lift. Furthermore, in order for force to be transferred effectively through the kinetic chain, body segments must be arranged so that muscle length-tension relationships are optimised and joint torque can be maximised. Therefore, a combined approach that considerers the isolated body segment lengths, in conjunction with how they interact to affect the entire barbell-lifter system is desirable. The coach should spend

time familiarising themselves with how different anthropometric segment lengths and ratios creates a correct SP, to enable them in setting the optimal SP for each lifter.

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List of Commonly Used Abbreviations

SN:	Snatch
SP:	Start Position
FP:	First Pull
TP:	Transition Phase
PP:	Power Position
SPL:	Second Pull
TOP:	Turn Over Phase
CP:	Catch Position
RP:	Recovery Phase
FRP:	Fully Recovered Position
MHBD:	Maximum Horizontal Barbell Displacement
AFL:	Absolute Femur Length
GRF°:	Ground Reaction Force Vector Angle

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Chapter 1 - Introduction

Over the last 10 years, the popularity of Olympic style lifting has increased considerably, where now many different individuals are taking part in performing these highly technical weightlifting movements. Olympic Weightlifting is a sport comprising of two competition lifts: the Snatch and the Clean and Jerk. The Snatch is where an athlete takes the bar from the floor to above head in one fluid, continuous motion (Ho *et al*., 2014). The Clean and Jerk is the second of the contested lifts and consists of two separate movements. Initially the lifter must retrieve the bar by taking the bar from the floor to shoulder height in one continuous motion. The clean is complete once the lifter is stood with the bar resting on their shoulders, the bar is then displaced above head using a jerk technique. To become competent at lifting heavy weights in these exercises a unique physiological profile is necessary that requires, a distinct combination of muscular strength, muscular power, flexibility, kinaesthetic awareness and technique (Fry *et al*., 2006). However, due to the mechanical nature of the Snatch, anthropometrics will influence the lifting style between individuals to a greater or lesser extent.

1.1 Role of Anthropometrics

Throughout Olympic lifting research regarding the "pull", the main focus has been on the path the bar takes, with little consideration given to the anatomical makeup of the body that is carrying out the lifting (Hancock *et al.*, 2012). That is until recently; Musser *et al.* (2014) conducted a study that examined the relationship between anthropometric data and horizontal barbell displacement during the pull phase of the Snatch in elite weightlifters. The results showed multiple thigh and trunk variables that significantly correlated with performance. Musser *et al.* (2014) concluded that understanding the relationships between anthropometry and barbell trajectory may be useful for optimizing the Snatch technique. This study also agreed with previous weightlifting research finding that longer trunks and relatively shorter limbs are more prominent in elite level lifters (Stone *et al*., 2006).

Previous research indicates individual anthropometrics affect Olympic lifting mechanics and technique (Ho *et al.*, 2014). The evidence suggests limb length ratios may influence the type of barbell trajectory, which is dependent on the movement of the mechanical levers created by the lifter (Ho *et al*., 2014 & Musser *et al*., 2014). Furthermore, the start position of the hips has been identified as a key factor in determining a successful lift (Ho *et al*., 2011), alongside the direction of force application from the start position (Gourgoulis *et al*., 2000). More research is needed to aid fellow scientists, coaches and athletes in understanding the Snatch lift, in more individualistic terms. Moreover, it would be beneficial to the field to provide new insight on whether an individual's anthropometric data can predict their optimal Snatch start position. Therefore, this thesis aims to address the question: does an individual's start position, based on their anthropometrics, influence kinetic and kinematic outcome measures of the Snatch?

Chapter 2 – Literature Review

When either coaching, describing or analysing Snatch technique, it is classically split up into phases; this allows for in-depth and informed coaching to be conducted. The phases are universal; meaning that regardless of the style of lifting an athlete uses, when performed competently, these phases will exist within the overall technique. A phase analysis is the common method for scrutinising the Snatch; where it is largely advocated that there are 6 key positions that make up the lift (Ho *et al*., 2014). The most commonly used language to represent the six phases of the Snatch (SN) are as follows: Start Position (SP), First Pull (FP), Transition Phase (TP), Second Pull (SPL), Turnover Phase (TOP), and Catch Position (CP). Other phases mentioned but less commonly discussed include the Recovery Phase (RP), (Derwin., 1990 & Chen *et al*., 2013) and the Fully Recovered Position (FRP) (Hydock 2001; Stone *et al.*, 2006; Ho *et al*, 2014). Even though these positions are discussed throughout literature there is no consensus as to what terminology should be used (Bartonietz, 1996; Gourgoulis *et al*., 2002; Musser *et al*., 2014); terminology and content of coaching Olympic Weightlifting can vary depending on the coach or scientist.

2.1 Literature Search Methods

The main literature sources for this review are from peer reviews journal articles, using the UCLan online journal catalogue, Google Scholar and Emerald database. In addition, pertinent coaching manuals were also sourced written by esteemed strength and conditioning practitioners, sports coaches and researchers. Key terminology and phrases used to develop this review included but not limited to: Olympic lifting, Snatch, start position, anthropometrics, bar path, barbell trajectory, phase analysis, technique analysis successful attempts, kinetics, ground reaction force and kinematics. Once literature was collected, all sources were grouped by categories then filtered based on relevance to the research question. Upon further analysis, sources were excluded from this review if there was to be a primary focus on irrelevant kinetic data e.g power. The most noteworthy scholars and most recent relevant studies were included in the following literature review.

2.2 Weightlifting in Sports

Implementation of Olympic Weightlifting movements in athletes' training programmes in a variety of sports has increased (Deweese *et al*., 2012; Suchomel *et al*., 2017; Soriano *et al*., 2019); resulting in increased participation in Olympic Weightlifting competitions. This increased implementation is potentially due to the similarities in muscle recruitment patterns and joint angles achieved at the hip, knee and ankle (Stone *et al*., 2006; Hori *et al*., 2008; Suchomel *et al*., 2017). This is most prevalent in movements which require triple extension during the SPL. This simulates comparable multi joint synchronicity with actions such as jumping, sprinting and change of direction (Hedrick and Wada., 2008 & Hori *et al*., 2008) (see ***Figure 1***). However, weightlifting movements provide a loaded stimulus not typically found in unloaded skills which require comparable joint actions (Suchomel *et al*., 2015). It can be inferred that the incorporation of weightlifting techniques results in greater performance transfer to other sporting actions. Through the utilisation of Olympic weightlifting's strength-power characteristics, improved sprinting and jumping performance can be observed when compared to traditional resistance-based training modalities (Kipp *et al*., 2012).

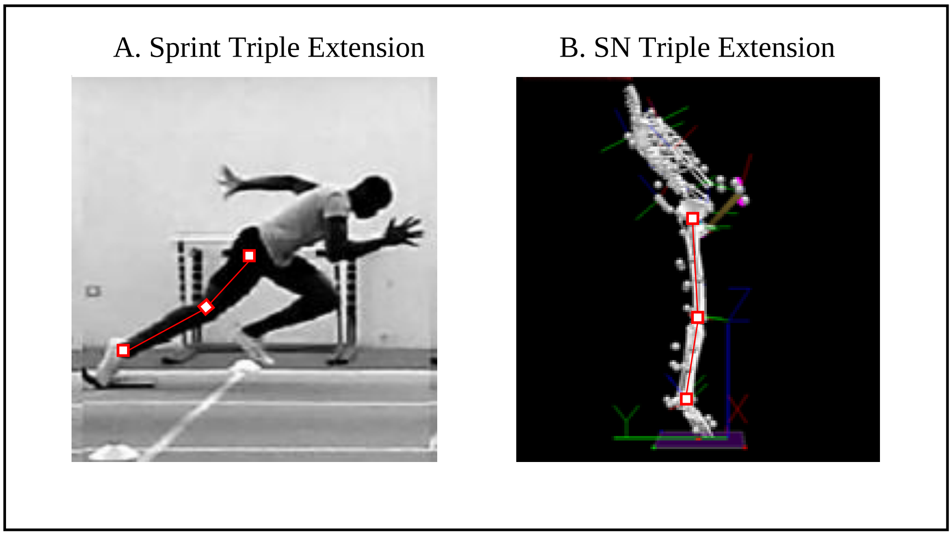


Figure 1. *This is a visual representation of the comparable joint angles achieved at the hip, knee and ankle. A. The triple extension of an initial acceleration stage of a sprint start (Goodwin et al.,2018). B. The triple extension stage of a SPL in the SN.*

It can be determined that the inclusion of weightlifting movements in strength and conditioning programmes improves sports performance (Garhammer., *et al* 1992; Hedrick and Wada., 2008; Suchomel *et al*., 2017) however, there are concerns relating to the time investment. Given the complex nature of the movements, to develop optimum performance the athlete would require dedicated workloads in their training to effectively acquire the skills (Hedrick and Wada., 2008). There are also specific injury risks associated with performing the full Olympic lift variations, (Stone *et al*., 1994) a potential factor practitioners should consider when constructing a training programme.

As a result of these concerns many practitioners have devised programmes that utilise Olympic lifting derivatives such as: SN and clean pulls that do not utilise the catch phase, and derivatives that exclude the SP and FP phases of the lift; known as hang variations (DeWeese *et al*., 2012; DeWeese *et al* 2013; Suchomel *et al.*, 2015). Hang variations require the athlete to attain positions where the bar begins at either the knee or mid-thigh (e.g. mid-thigh pull, clean/SN from the knee). The implementation of these derivatives allows the mid-thigh position, which is considered the strongest and most powerful position (Suchomel *et al.*, 2015) to be overloaded. Hang variations can be performed from weightlifting training blocks or from squat rack safety bars. These are known as static starts where there is a need to overcome inertia from a dead stop position. These can also be performed from a dynamic start; lowered from hip position down to knee/mid-thigh or from a held stationary position (Suchomel *et al*., 2017). Certain variations will create a different demand for the athlete, which should be considered by practitioners prior to exercise prescription.

The exclusion of the SP and FP reduces the technical demands of the SN/clean, making them easier to learn. Allowing the athlete to maximise the benefits of overloading the triple extension without being concerned with the complexities associated with the double knee bend or required positional demands seen at the SP. Especially when considering that if there is breakdown at the SP the SPL cannot be optimised (Everett, 2009 & Ho *et al*., 2011). Therefore, the benefits of performing the exercise for sport transference will be diminished. It can be supported that for athletes to reap the benefits of Olympic lifting, technique would play a large part in the performance carry over. As it is deemed necessary to remove the SP to facilitate effective sporting transfer, this justifies the importance of an aspiring weightlifter to master their optimal SP.

2.3 Phase analysis

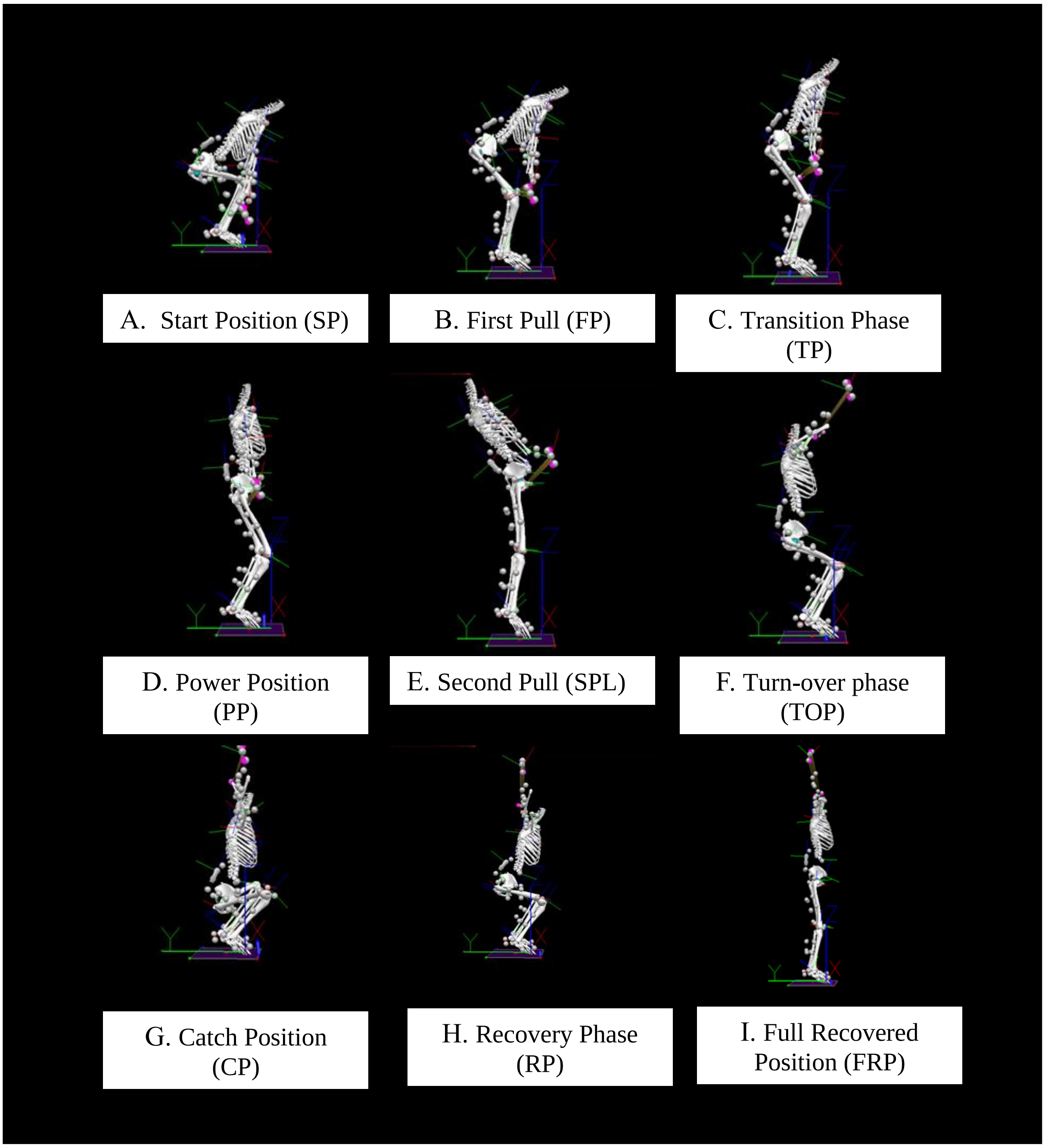


Figure 2. *Phase Analysis. A full breakdown of each phase of the Olympic lift the SN.*

2.3.1 Start Position

SP prepares the lifter for initiation of movement (*see **Figure 2**.A*). For the purpose of this study, the SP will refer to the instance the separation occurs between the barbell and the floor. This is the instant the barbell and the lifter become a combined system. On approach to the barbell, lifters will position themselves centrally, then in no specific order foot stance and grip width are obtained before setting a desired hip position.

Grip Width

The lifters will assume SN grip, where the width is as wide as the lifter is suited too. There is no formula to determine grip width, however a quick method is to hold the bar at arm's length, using hook grip (see **Figure 3**) (Turner & Comfort, 2017) whilst stood upright, adjusting the bar until it is sitting in the hip crease (Everett, 2009).

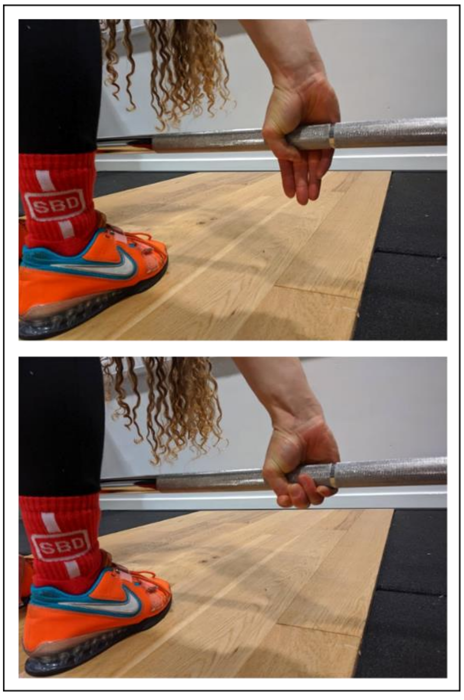


***Figure 3**. Hook Grip. Desired grip style for Olympic Weightlifting movements*

Foot Position

Two factors that present interparticipant variance are stance width and toe angle position. A common consensus is that the basic pulling position of the feet is approximately hip width apart and slightly externally rotated (Everett, 2009). However, this may not be optimal for all lifters based on flexibility, anatomical structures and anthropometrics. Further research into this area would benefit current coaching of Olympic lifting.

Therefore, the main coaching point utilised is to ensure the barbell is positioned approximately over the midpoint of the feet (Ho *et al*., 2014; Aita, 2017; Turner & Comfort, 2017).

Foot Pressure at the SP

Foot pressure is an important factor when performing Olympic Lifts and should be adjusted in conjunction with the phases of the movement. At the SP, pushing into the ground through the middle of the foot is desirable (Turner & Comfort, 2017).

Setting the Hips

Once the appropriate grip width and foot position are established; the knees and hips should be in flexion, whilst the ankles are in dorsiflexion. Generic coaching points typically utilised at this phase are that the hips should be higher than the knee joint centre and the shoulders should be above the hip joint centre (Turner & Comfort, 2017). However, as knowledge and understanding of the movement advances, it can be theorised that this is not applicable to all participants due to differences in genetics, anthropometrics and mobility.

Setting the Torso

There is also a lack of consensus for shoulder position relative to the bar at the SP. The most common conflicting coaching cues presented in the literature are: shoulders inclined over/in front of the bar (Deweese 2012; Musser *et al*., 2014; Turner & Comfort, 2017) and an upright back angle should be achieved (Everett, 2009) thus placing the shoulders in line with the bar. However, in a similar manner to hip position, an individual's characteristics (particularly trunk to femur ratio) can be important factors in determining which position leads to optimal performance. Generic coaching cues such as "lift the chest" and "pull the shoulders back" (Favre & Peterson, 2012; Turner & Comfort, 2017) can be more relatable to weightlifters. These will help to facilitate the natural curvature of the spine, by eliciting the appropriate amount of thoracic extension. ***Figure 4***, demonstrates the appropriate implementation of the natural curvatures, thus achieving the desired spinal position. If spinal position is compromised this may affect the force produced by the hip extensors, which in turn could dictate the success of the lift (DeWeese *et al*., 2012).

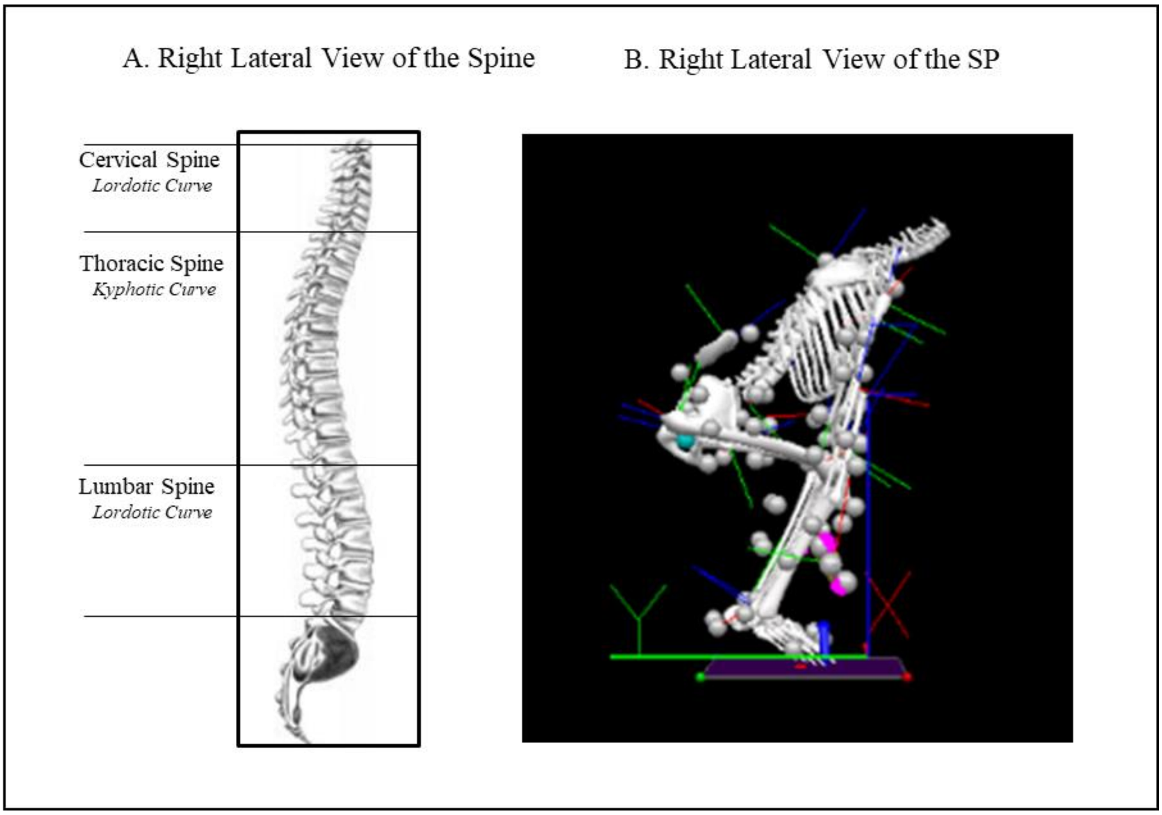


Figure 4. *Natural curvatures of the spine. A. Is a diagram which dissects the natural curvatures of the spine (Salem et al., 2015). B. Is a visual representation of a SP for a SN lift.*

Pulling the Slack

It is also advisable for the elbows to be turned out (shoulder internal rotation) and for the arms to be fully extended but with some degree of scapular retraction and elevation, which aids in pulling the slack out of the barbell (Turner & Comfort, 2017). This phenomenon has been alluded to throughout strength-based sport literature but has not been thoroughly explored. Once the lifter has finalised their grip and foot position they should use the barbell to pull themselves into the SP. This can be achieved by actively using the barbell to extend the arms and spine. This creates the desired tension at the barbell.

The SP is an important technical element for any form of pulling movement from the floor, especially Olympic lifts. The separation between the bar and the floor needs to be a smooth transition; setting up the remainder of the lift (Ho *et al*., 2014; Favre & Peterson, 2012). If there is an insufficient amount of tension at the SP, there is a higher likelihood of neutral spine position breakdown as the bar leaves the floor. This may affect the outcome of the lift (Favre & Peterson, 2012).

Common faults at the SP

It can be determined that a SP with a higher hip position where the shoulders pass too far over the bar can cause the neutral spine position breakdown. A position where the spine becomes more parallel to the floor would increase the likelihood of a convex curve of the thoracic spine; resulting in decreased performance (DeWeese *et al*., 2012).

2.3.2 First Pull

Once the lifter has obtained the SP the next phase of the lift can begin. The FP phase commences when the barbell and the lifter become a combined system; identified as the instance after the bar leaves the floor. As the bar elevates, knee extension initiates, accompanied by simultaneous upward movement of the hips. The phase is completed once the bar has reached knee height (*see **Figure 2**.B*). This results in a position where the shoulders are over the bar, the knees are slightly flexed, and the torso angle remains constant from that created at the SP (Stone *et al.*, 2006 & Kipp *et al*., 2012).

Knee Flare

Knee flare describes the external rotation of the hip adopted at the SP; this can help to maintain an upright torso angle which is a desirable characteristic for this phase (Everett, 2009). By attaining this position, it is less likely the shoulders would be forced downwards and forwards as the knees begin to extend; causing the torso angle to be jeopardised (Favre & Peterson, 2012). In addition, the knees do not have to translate backwards as far in order for the bar path to be almost vertical.

Foot Pressure at the FP

As the barbell begins to elevate from the SP and approaches the end of the FP foot pressure is transferred from the mid-foot to the heels. This occurs as the knees extend and the hips rise (Turner & Comfort, 2017).

Common faults of the FP

On commencement of the FP a common error such as an athlete beginning to raise the hips prematurely creates a situation where the chest drops, and the torso angle alters, thus making it difficult for the desired spinal position to be maintained. Furthermore, some athletes initiate the FP through the balls of their feet and toes as opposed to the midfoot

(DeWeese *et al.*, 2012).

2.3.3 Transition Phase

During the TP, the barbell continues to elevate from above the knee (end of FP) to the top of the femur (*see **Figure 2**.C*), commonly referred to as the hip crease (Everett, 2009; Turner & Comfort, 2017). This identifies the transition from FP to SPL *(See **Figure 2**.E*). Primarily, this phase prepares the barbell-lifter-system for the SPL; the explosive phase of the movement. This is done by repositioning the body relative to the barbell through the double knee bend action (Hadi *et al.,* 2012 & Musser *et al*., 2014).

2.3.3.1 Double Knee Bend

The double knee bend displays an extension- flexion- extension pattern of the knee joint. Beginning at the SP, as the bar elevates, the knees move backwards into extension facilitating the bar to take a straighter line, as the bar reaches knee height this marks the end of the FP (Everett, 2009). As the bar passes the knees, they re-enter flexion and repositions under the bar (Stone *et al.,* 2006; Turner & Comfort, 2017). This second knee bend eccentrically loads the quadriceps and better aligns the body to pull the bar forcefully. The bar continues to elevate until reaching the hip crease in preparation for the final knee extension that occurs in the SPL; this is referred to as the power position (Winwood *et al.*, 2015).

2.3.4 Power Position

The power position (PP) can be characterised as the shoulders, hips and heels being in line (Ho *et al*., 2014, Turner & Comfort, 2017). The torso should be at a near vertical position, with the arms extended and knees bent under and in front of the barbell (Ho *et al*., 2014) (*see **Figure 2**.D*).

It can be speculated that when the double knee bend is performed rapidly with superior joint coordination, the stretch-shortening cycle (SSC) could be identified (Isaka *et al.,* 1996; Gourgoulis *et al.,* 2000; Stone *et al.,* 2006). The mechanism which initiates an effective SSC can be associated with the Olympic lifts, at the instance where the knees move into flexion and eccentric lengthening of the quadriceps occur. This should be immediately followed by a rapid concentric muscle action during the consecutive knee and hip extensions (Cavanagh and Komi, 1979; Butler *et al.*, 2003; Stone *et al*., 2006); this facilitates a more effective SPL (Ho *et al.*, 2014).

Foot Pressure at the TP

During the TP, the double knee bend allows for foot pressure to be shifted forward from the heels to the mid foot (Stone *et al*., 2006; Turner & Comfort, 2017). Pressure can translate further towards the lifter's toes; depending on the amount of forward knee travel used during the second knee flexion at the TP.

Common faults of the TP

Due to the complex nature of the TP, mistakes commonly manifest due to errors in timing or joint coordination. Common errors identified include: an athlete keeping their chest ahead of the bar and not shifting to the near upright power position, an athlete may not re-bend at the knees (double knee bend) which can also result in the chest rising too slowly whilst approaching the power position (DeWeese *et al.*, 2012). Additionally; the athlete may begin the SPL prematurely, where the barbell makes contact on the lower part of the thigh as opposed to the hip crease upon approaching the SPL. A potential cause for this is an early arm bend through the TP.

2.3.5 Second Pull

From the PP (*see **Figure 2**.D*), the lifter transitions to the SPL; the phase of the movement with the highest level of mechanical power generation (Gourgoulis *et al*., 2000). When performed optimally, the bar contacts the lifter's hips/upper thighs (depending on anthropometrics) whilst the lifter pushes into the ground and rapidly extends their hips, knees and ankles (plantar flexion). With a final shrug of the shoulders the body reaches full extension (*see **Figure 2**.E*). The simultaneous extension of the hips, knees and ankles is known as the triple extension (Everett, 2009; Turner & Comfort, 2017).

Foot Pressure at the SPL

As the lifter moves from the TP to the SPL, a quick and effective transition to ankle plantar flexion is required for the triple extension. Here foot pressure continues towards the end of the lifter's toes.

Barbell height

During the SPL it has been proposed that minimizing final bar elevation may be advantageous, as it results in less total work done prior to the subsequent TOP (*see* ***Figure 2****.F*) (Hadi *et al.*, 2012). However, a higher bar elevation prior to the TOP can provide the lifter more time to rapidly squat under the bar/ pull themselves under bar to catch it in a stable position (Campos *et al*., 2006; Ho *et al*., 2014). Lifters should aim to keep their arms extended for as long as possible during the SPL to ensure maximum force transfer to the barbell (Turner & Comfort, 2017). However, due to upward momentum of the barbell the athlete's arms will begin to bend as they begin the next phase of the lift.

Common faults of the SPL

Although it is crucial to transfer foot pressure towards the toes, if this action is performed too early, it can cause the hips to move too far forward; potentially resulting in unwanted looping of the barbell leading to a compensatory jump forward by the lifter (Everett, 2009; Deweese *et al*., 2012; Musser *et al*., 2014; Aita, 2017). Another common error comes from an incomplete triple extension, where the hips knees and ankles have not been fully extended. This error, in conjunction with a lack of shoulder shrugging at the top of the movement, leads to an incomplete SPL. This can influence the barbell height achieved.

<u>2.3.6 Turn Over Phase</u>

The TOP proceeds the SPL, beginning when the lifter starts to descend, the barbell continues its upward trajectory created by the triple extension (*see* ***Figure 2****.F*). During the TOP the lifter's body travels downwards whilst pulling themselves under the bar (Hydock *et al*., 2001), with significant help from the deltoid and bicep muscle groups (Chen *et al.*, 2013). This is achieved by rotating the hands and elbows around the barbell, moving from a fully extended position above the barbell into a flexed position below the barbell (Turner & Comfort, 2017) (*see* ***Figure 2****.E&F*).

Maximum barbell velocity is typically achieved during the TOP (Himawan *et al.*, 2018). The barbell continues its upward trajectory until reaching maximum height, until velocity reaches zero (Everett, 2009). At this point the barbell is momentarily stationary, where the lifter should complete their pull under the barbell and fully extend the elbows, locking out the arms above head. The elbows should lock out simultaneously as the feet land flat on the floor. There may also be a change in foot stance where the feet have shifted slightly outwards from the SP in preparation for a more stable CP (Turner & Comfort, 2017).

2.3.7 Catch Position

After locking out the barbell, the lifter will continue to descend, flexing at the hips, knees and ankles (Dorsiflexion) into an overhead squat start position (*see* ***Figure 2****.G*). This is known as riding the barbell down and is primarily seen in advanced lifters. This is then followed by an amortization of the barbell's downwards momentum as the lifter affixes their CP (Aita, 2017). The maximum barbell velocity and speed the lifter pulls under the bar, during the TOP, will determine bar descent before being stabilized at the CP.

Common faults of the CP

Mistiming of the CP can be the result of a lifter pulling the bar higher than necessary during the SPL and then squatting lower than needed during the TOP. This can result in the bar crashing down on the lifter at the CP. Therefore, causing greater difficulty for the lifter to fixate the barbell above head, increasing the risk of an unsuccessful lift (Aita, 2017). As a by-product of mistiming the CP, the downward momentum of the barbell may not be able to be amortised optimally, causing the arms to re-bend, which is considered a no lift (British Weightlifting, 2019).

2.3.8 Recovery Phase

Once the bar is stabilized above head, the lifters will perform an overhead squat. This is done by maintaining an upright torso position, whilst extending at the knees and hips to a standing posture (Turner & Comfort, 2017) (*see* ***Figure 2****.H & I*). The glenohumeral joint should remain directly under the barbell for the duration of this phase (Chiu & Burkhardt, 2011) whilst maintaining full foot contact on the floor and appropriate knee position. As the RP requires a large amount of stability (Everett, 2009) this can reduce the anterior/posterior and medial/lateral movement of the bar caused by instability during this phase. Therefore, reducing the requirement of the lifter to adjust their Centre of Mass, re-establish a strong base or regain control prior to transition to FRP.

In advanced/experienced lifters there can be rapid transition from the CP into the RP, commonly known as "catching the bounce". This is where the elastic energy in the loaded muscles, created by the descending lifter and the downwards momentum of the bar, is used to propel the lifter upwards through the RP into the standing position.

2.3.9 Fully Recovered Position

The lift can be considered complete when the lifter is standing upright, the bar is stabilised above head with elbows, knees and hips in an athletically straight position and feet are in line and parallel to the bar (Ho *et al*., 2014) (*see **Figure 2.1***).

Foot Pressure to FRP

When transitioning from the CP to the FRP, it can be seen to be more beneficial to maintain full foot contact. This allows pressure to be transferred to the lateral aspect of the foot and heel, enabling a larger distribution of pressure (Kushner *et al*., 2015). Without sufficient support from foot position, force production and squat performance can diminish. Optimal squat performance requires the whole foot to be in contact with the ground throughout the duration of the CP and FRP.

Foot pressure during the ascent of a squat can vary between individuals based on flexibility (Kushner *et al*., 2015), muscular strength (Yoon *et al*., 2018), weight distribution (Da *et al*., 2015), stance width and foot structures (Escamilla *et al*., 2001). Foot pressure during the ascent of the squat requires further investigation to fully determine the effect it has on performance.

Common faults to the FRP

Overhead stability is crucial for the RP especially when approaching the FRP (Chiu & Burkhardt, 2011). Kinetic energy of the barbell declines during the final stages of the RP, this is because the lower limb musculature applies less impulse, thus placing a higher demand on the upper body musculature (Chen *et al*., 2013). If appropriate stability is not obtained during the FP, this can lead to the lifters having to walk forward to prevent the barbell from drifting forward ahead of the glenohumeral joint or the barbell is lost forward resulting in a failed lift.

2.4 Barbell Trajectory

The barbell-lifter system follows the previously outlined phases from SP to FRP and when done effectively and in synchronicity, it produces a trackable barbell trajectory (*See **Figure 5**)*. When analysed, SN barbell trajectory typically forms a unique S-shaped pattern. This is the result of the utilization of natural mechanical levers and the transfer of momentum by the participant throughout the lift. Thus, creating both horizontal and vertical displacements (Ho *et al*., 2014).

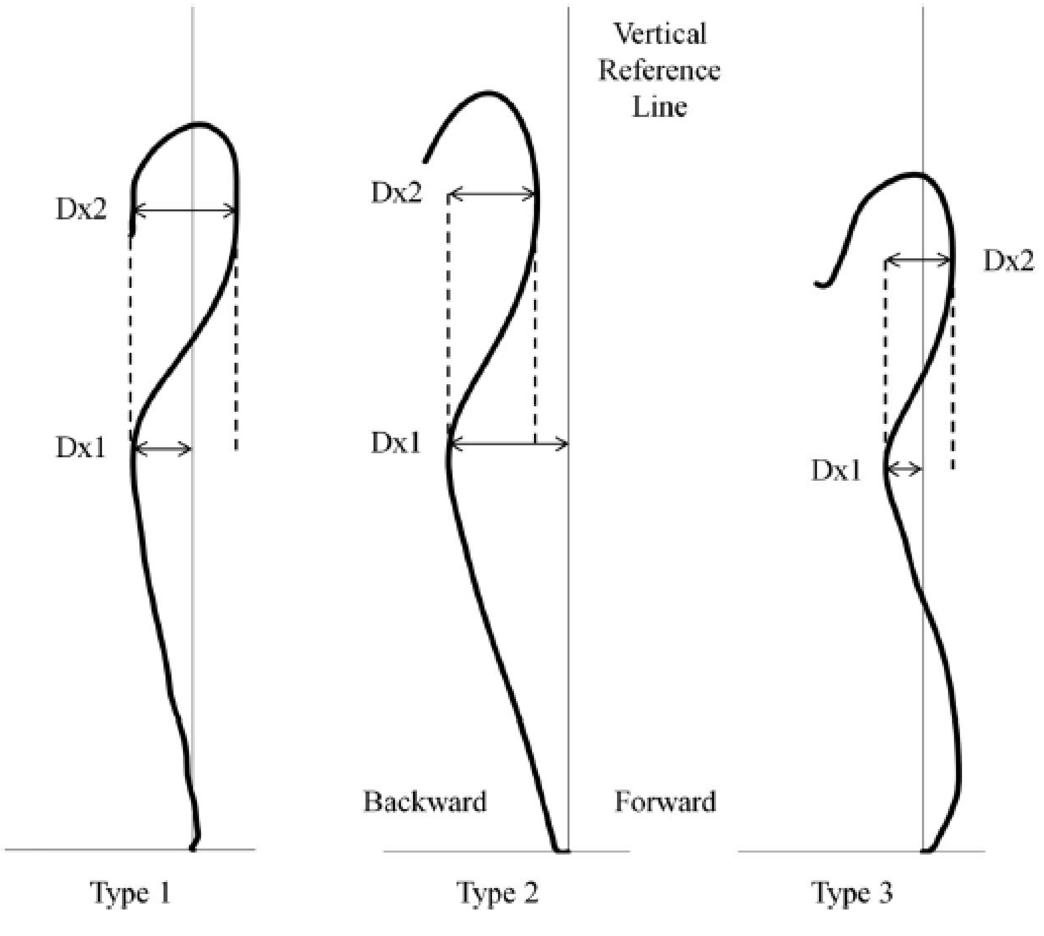


Figure 5*. Barbell Trajectory Types. Including maximum first pull horizontal displacement (DX1) and maximum second pull horizontal displacement (DX2) (Musser et al., 2014).*

Barbell Trajectory analysis is an advanced measure for critiquing weightlifting technique; it can be used to observe and quantify the S-shaped pattern (Bartonietz, *et al*., 1996) typically found in the SN. Barbell trajectory provides insight into the displacement of the barbell in both the vertical and horizontal direction (Musser *et al*., 2014). This is determined by a vertical reference line transecting the sagittal plane, initiating from the barbell start position (Stone., *et al* 1998). Accurately analysing barbell trajectory along with the vertical and horizontal displacements involved are useful for scientific enquiry and coaching critiques. Barbell Trajectory is considered a strong performance indicator (Bartonietz, 1996; Byers *et al*., 2008; Gourgoulis *et al*., 2002; Gourgoulis *et al*., 2000; Ho *et al*., 2014).

There are three identified Barbell Trajectory Classifications (BTC) (Ho *et al*., 2014). Musser *et al.* (2014) outlines these classifications as Type 1, Type 2 and Type 3 (*see **Figure 5***). Type 1 is considered the optimal BTC due to the lowest level of horizontal displacement. The barbell passes the vertical reference line during triple extension and again during the transition to the CP. This displays a towards-away-towards pattern of the barbell (Hadi *et al*., 2012 & Gourgoulis *et al*., 2000). During a type 2 BTC, the barbell does not pass through the vertical reference line throughout the lift and instead travels towards the lifter. The barbell still displays a towards-away-towards pattern (Musser *et al*., 2014). A type 3 BTC is the least optimal classification as it crosses the vertical reference line at 3 points and does not follow the towards-away-towards pattern (Musser *et al*., 2014 & Stone *et al*., 1998). The barbell moves away from the lifter as it leaves the floor. Greater anterior-posterior deviation from the vertical reference line in type 3 BTC results in suboptimal performance (Gourgoulis *et al*., 2009 & Hadi *et al*., 2012).

Gourgoulis *et al.* (2009) conducted an interesting study whereby his results showed that there was no significant difference in the kinematic characteristics between successful and unsuccessful SN attempts. These characteristics included first and second maximum hip and knee extension and ankle dorsi flexion, position of the lifters body and their limbs relative to the barbell. Kinetic variables analysed included maximum velocity, the instant of maximum velocity achieved and absolute velocity, all of which were seen to be significantly similar between successful and unsuccessful SN attempts. The only significant factor that impacted a successful SN attempt was the direction of the forces applied on to the bar from the SP to the FP. Signifying the importance of correct force application from commencement of the lift to allow the barbell to travel in a desired trajectory. Furthermore, much like Ho *et al.* (2014) & Isaka *et al.* (1996), Gourgoulis et al. (2009) highlighted the importance of minimising anterior-posterior movement and maximum horizontal displacement of the barbell to reduce energy loss and achieve an effective lift. Thus, further supporting the position of Musser *et al*. (2014) & Hadi *et al*. (2012) that a trajectory that represents a BTC similar to that of Type 1 and Type 3 where the barbell is travelling backwards towards the lifter through the initial phases, is more desirable in achieving a successful lift. In addition, it was demonstrated by Chen & Chiu. (2011) that the smaller the angle is between the barbell, 7th cervical spinous process and the hips; keeping the barbell closer to the body, throughout the pulling phases results in a more successful SN technique. Furthermore, the results of this study also suggested that catching the barbell in a backwards trajectory is also desirable for successful SN attempts. Thus, indicating the importance of an effective barbell trajectory throughout the entire lift, however the initial direction from the SP can influence the successfulness of a SN (Gourgoulis *et al*., 2009; Ho et al., 2011; Favre & Peterson, 2012). Much of previous research that has analysed barbell and lifter kinematics has focused on the differences between each phase of the lift collectively across any single testing group. There is limited research into analysing Olympic weightlifting athletes on an individual basis and the implications that individual characteristics may have on barbell kinematics.

2.5 The Importance of an Optimal SP

In recent years a consensus has been reached, that lifters SP's are imperative in determining the outcome of a successful SN lift (Ho *et al.*, 2011). Due to the small-time frame for the bar to travel from the floor to above the lifters head, minimal room for error exists. An experienced and technically proficient weightlifter may achieve a successful full SN in 2-3 seconds (Everett, 2009). This is comparatively much quicker than other pulling movements such as the deadlift. The deadlift is a slower movement from start to finish, especially at maximum loads (Hydock *et al.*, 2001). Therefore, an athlete has more time to compensate and a larger degree of freedom for technical breakdown from a suboptimal SP. Unlike the SN, which by nature is a quicker movement with a lesser degree of freedom. Providing less opportunity to adjust technique during the movement, showing the importance of an optimal SP.

There is mounting evidence that lifters SP's are relative to their height, body mass, somatotype and body proportions (Musser *et al*., 2014; Aita, 2017; Turner & Comfort, 2017). Ho *et al.* (2011) conducted a case study on an individual weightlifter and concluded that the weightlifter had an optimal SP hip angle (hip angle of 89.6°). If the hip angle had been smaller, the chance of a successful lift fell to 27%. Based on Ho *et al's*. (2011) research it could be advocated that each individual weightlifter has an optimal SP hip angle. This is based on their anatomical proportions, facilitating them to perform the SN optimally. Furthermore, acceptance of the importance of anthropometrics and their effect on SP is increasing within relevant literature. The primary consideration being relative length of femur to torso (Aita, 2017; Musser *et al*., 2014). On average, higher ranked Olympic Weightlifters have long torsos and comparatively shorter femurs than lesser ranked lifters (Musser *et al*., 2014). Higher ranked lifters tend to adopt a relatively lower hip height position at the SP in contrast to lifters with shorter torsos and longer femurs (Stone *et al*., 2006 & Aita, 2017). Optimal SP hip height could allow lifters to form a posture which based on their anthropometrics, would allow them to efficiently produce force and utilize lever arms to generate the largest amount of torque.

A lower hip position would require a larger knee angle and less torso lean, resulting in a shorter lever arm at the knee where the quadriceps would generate the predominant force. Contrasting with a higher hip position, where less knee bend and greater torso angle are required; resulting in a larger lever arm at the knee. This shifts the generation of force towards the lower back and hip musculature (Zajac 2002; Aita, 2017). Different SPs could be pre-determined by an individual's anthropometrics; therefore, by repositioning their body to maximise the relationship between leverage and force production, the likelihood of a successful lift being achieved is enhanced. Thus, furthering the suggestion that each individual lifter has an optimal SP, which is based on their relative anthropometrics.

2.6 Aims and Hypotheses

The aim of this research is to provide insight into the relationship between anthropometric characteristics and adopted SP and the influence this may have on kinetic and kinematic variables at the SP.

In order to address the primary research question, three objectives were established, which were:

1) Identify which anthropometric variables predict the start position of the Snatch.

2) Identify which anthropometric variables predict the angle of the force vector during the first pull.

3) Identify which anthropometric variables predict the direction of the bar path from the start position to the end of the first pull.

For objective one, it was hypothesised that trunk and femur ratios will be the best predictors of the adopted hip height at the SP. For objective two, it was hypothesised that relative trunk and femur lengths and ratios will be the best predictors of the force vector angle during the FP. Finally, for objective three it was hypothesised that trunk and femur lengths and ratios will be the best predictors of the direction of the bar path from the SP to the end of the FP.

Chapter 3 -Methodology

3.1 Participants

Experience level is a more recent consideration when recruiting for Olympic lifting studies. It is understood that the number of years an athlete has been performing these Olympic lifting movements will influence the dependability of the results found. Especially when considering these are complex motor skills that require considerable practice over time to attain a high level of consistent skill mastery (Musser *et al.*, 2014). This study recruited 20 male participants with an average age of 29.5 ± 5.3 yrs. Body mass has been shown to influence barbell trajectory (Musser *et al.*, 2014), therefore the average body mass was 77.5 ± 8.0kg as all participants were required to weigh between 62kg and 94kg, in accordance with the International Weightlifting Federation (IWF) weight class systems of 2018. The experience level of the participants ranged from 2-15 years, with an overall average of 5.6 ± 4.9. Participants were required to have a minimum of 2 years lifting experience or be at a national level in the sport of Olympic Weightlifting. Olympic lifting must have been part of their weekly training schedule over the two years. These requirements were to ensure the participants had a desired level of competency and had developed a repeatable technique. All potential participants that met the inclusion criteria, but were currently injured, were excluded from partaking in the study.

Prior to testing a participant information form was sent to each participant. Participants were given 3-5 days to decide if they would like to volunteer to take part in the study. A date and time for testing was arranged between the participant and the researcher. On the day of testing before data collection commenced, written informed consent was given by the participant along with a PARQ+1 form, which was signed off by the researcher. This research has been reviewed and approved by the University of Central Lancashire: STEMH Ethics Committee (STEMH 905).

3.2 Protocol

3.2.1 General Warm Up

Before lifting commenced, participants submitted their self-reported one repetition maximum (1RM). The average mass submitted was 75 ± 12.5kg, where 85% was 65.0 ± 10kg (rounded to the nearest 1.25kg). This was indicative of the most mass lifted, successfully in the SN, within the past 3 months for an accurate representation of their current strength. This was recorded so that the appropriate weights to use for the testing process could be calculated. Each participant was then instructed to conduct their individual warm up including mobilization, activation drills and dynamic stretching as required. It was advised that the warm up protocol replicated what the participants would normally perform before a SN lift training session.

3.2.2 Anatomical markers

To collect kinematic data for analysis 19mm spherical reflective markers were placed bilaterally, on all relevant anatomical landmarks (see **Table 1**). This was conducted in accordance with the research conducted by Cappozzo (1995). Joint centres were calculated by the midpoint between the lateral and medial, distal end segment markers. Tracking clusters (s*ee* ***Figure*** **6**), were also positioned along the long axis of the thigh, shank, upper arm and forearm similarly to the marker set used by Chen *et al.* (2013). Tracking clusters were also placed on the lumbar spine, between PSIS and T12, as well as the thoracic spine between T12 and C7 segments. All tracking clusters were comprised of four 19mm reflective markers screwed to a thin sheath of light weight carbon fibre. The length to width ratio of each cluster is 1.5-1, as recommended by Cappozzo *et al*. (1997). In order to minimise error and strive for consistency in placement of the anatomical markers, the researcher was the only person to marker up participants in preparation for the testing protocol. The researcher had ample experience with this process after previously receiving formal guidance whilst completing a 10-week internship where this marker set was used and over 100 participants were tested.

A segment coordinate system that provides reliable and consistent movement interpretation is crucial when acquiring kinematic data (Sinclair *et al*., 2012). Therefore, for all segments the positive Z (transverse plane) axis was defined in the direction of distal to proximal joint centres. The positive Y (coronal plane) axis was defined as perpendicular to the Z axis and the X (sagittal) axis was portrayed as a cross product of the Y and Z axes.

3.2.3 Barbell Markers

Six markers were also placed on the barbell; three on each end. Two were placed on the shaft, which were used to define the barbell as a segment in the Visual 3D software, one on the centre point of each end of the barbell to enable barbell trajectory analysis (Ho *et al.*, 2011). This provided an effective method of tracking the barbell- lifter system, see ***Figure 7*** for a full visual representation of the anatomical model.

Table 1. Table of all anatomical and barbell markers and four-point clusters.

ANATOMICAL LANDMARKS- ***Appendicular Skeleton***		
Left Acromion Process	Left Trochanter of the Femur	Left Calcaneus
Right Acromion Process	Right Trochanter of the Femur	Right Calcaneus
Left Medial Epicondyle of the Humerus	Left Medial Epicondyle of the Femur	Left 5th Metatarsal
Left Lateral Epicondyle of the Humerus	Left Lateral Epicondyle of the Femur	Right 5th Metatarsal
Right Medial Epicondyle of the Humerus	Right Medial Epicondyle of the Femur	Left 1st Metatarsal
Right Medial Epicondyle of the Humerus	Right Lateral Epicondyle of the Femur	Right 1st Metatarsal
Left Styloid Process of the radius	Left Medial Malleolus	
Left Styloid Process of the Ulna	Left Lateral Malleolus	
Right Styloid Process of the radius	Right Medial Malleolus	
Right Styloid Process of the Ulna	Right Lateral Malleolus	
ANATOMICAL LANDMARKS- ***Axial Skeleton***		
Cervical Spine 7	Left Iliac Spine	Left Posterior Sacrum Iliac Spine
Thoracic Spine 12	Right Iliac Spine	Right Posterior Sacrum lilac spine
Xiphoid Process		Left Anterior Superior Iliac Spine
		Right Anterior Superior Iliac Spine
Four Point Tracking Clusters		
Left Lower Leg	Left Upper Arm	Lumbar Spine
Right Lower Leg	Right Upper Arm	Thoracic Spine
Left Upper Leg	Left Forearm	
Right Upper Leg	Right Forearm	
Barbell Markers		
Left Anterior Barbell	Left Posterior Barbell	Left Barbell End
Right Anterior Barbell	Right Posterior Barbell	Right Barbell End

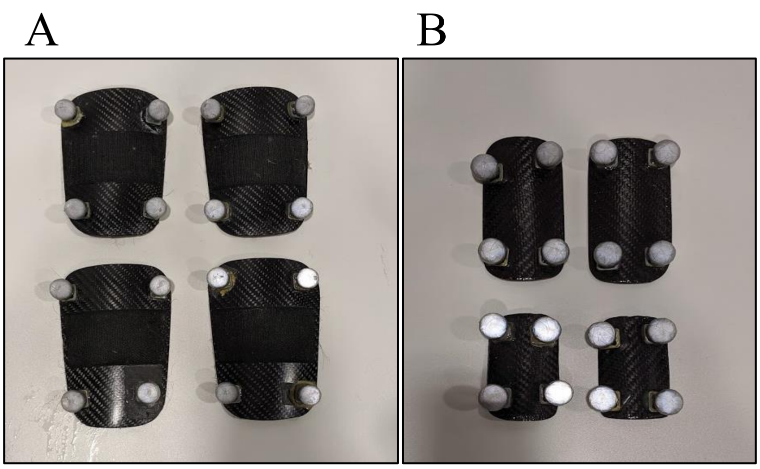


Figure 6*. Carbon fibre tracking clusters. A- Lower Limbs, B- Upper Limbs.*

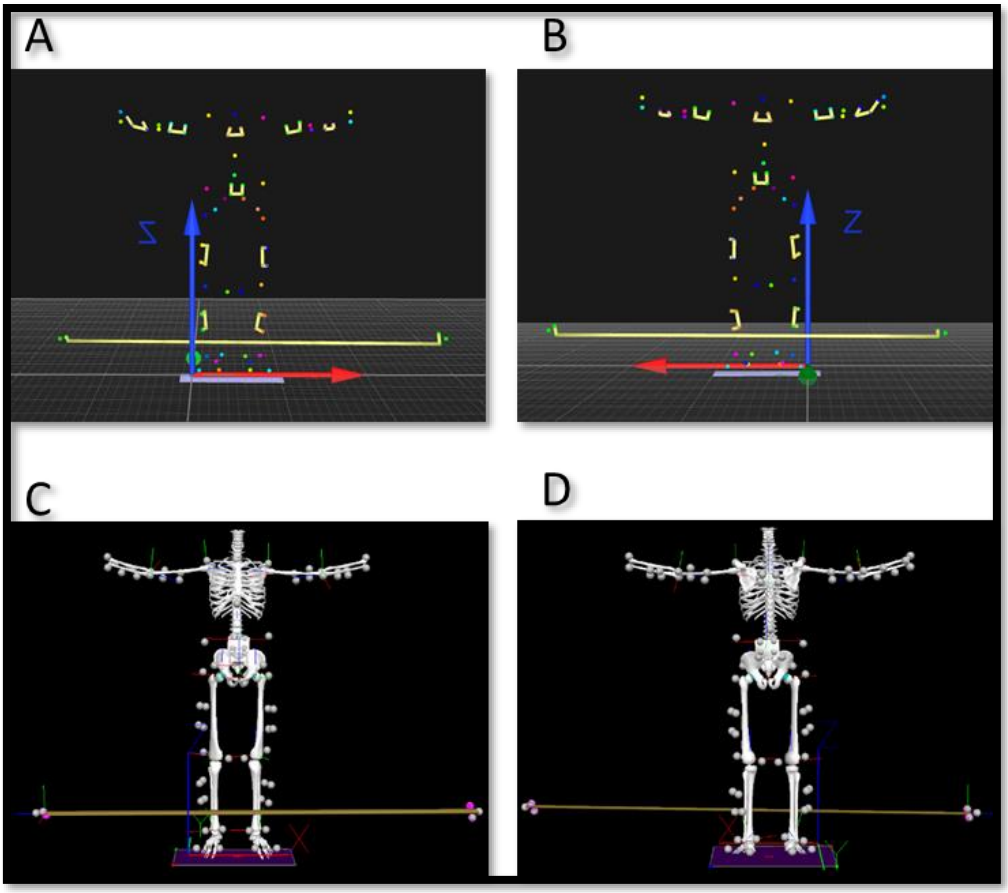


Figure 7*. Anatomical Posture. A; QTM labelled marker set anterior view, B; QTM labelled marker set posterior view, C; V3D full body model anterior view, D; V3D model body posterior view. V3D segments include a barbell, pelvis and a trunk as well as both left and right: feet, shank, thigh, upper arm, lower arm and hand.*

3.2.4 Specific Warm Up

Once the participants had been prepared for testing, and after all the reflective markers were attached correctly, a specific warm up protocol was performed. This was in addition to the general warm up and was approximately 10 minutes long and consisted of progressive and relevant full body movements. This included derivatives of the SN movement (e.g. overhead squats, SN balance, SN high pull etc.) that replicated what the participants would normally do prior to a SN lift training session. The amount performed of this extensive warm up protocol was under the discretion of each participant; this gave the participants freedom to get physically and mentally prepared, as they normally would for the SN lift. This also allowed them to get comfortable in the new environment, whilst wearing the full marker set.

The specific warm up naturally progressed in to the full SN; this is where the researcher discussed and then instructed the participant what weight plates to add to the barbell, with the goal to incrementally increase to the desired 85% of 1RM. Based on the self-reported 1RM for each participant a generally advised progression was as follows: 5 repetitions with the barbell alone (Gym Gear, Elite 7ft Olympic bar) with 1-minute rest, followed by 5 repetitions at 30% of 1RM with 2 minutes rest, then 3 repetitions at 50% of 1RM with 2 minutes rest. There was then a single repetition taken at both 65% and 75% of 1RM with 2 minutes rest between each attempt (Winchester *et al*., 2009). Official testing and data collection of the lifts then commenced. This protocol was adapted, if required, under the discretion of the participant and when they felt ready to move to the next weight selection.

3.3 Testing Protocol

Once the barbell weight reached the desired 85% of 1RM, the required six reflective markers for the barbell were then added. A static trial of both the participant and the barbell was then taken: the participant was asked to stand with both feet on the force platform, facing the computers with the barbell in front of them (*see* ***Figure 8***), whilst in the anatomical position: feet shoulder width apart, arms out to the side at eye level and thumbs facing the ceiling. If any of the cluster plates moved during any of the trials this process would then be repeated.

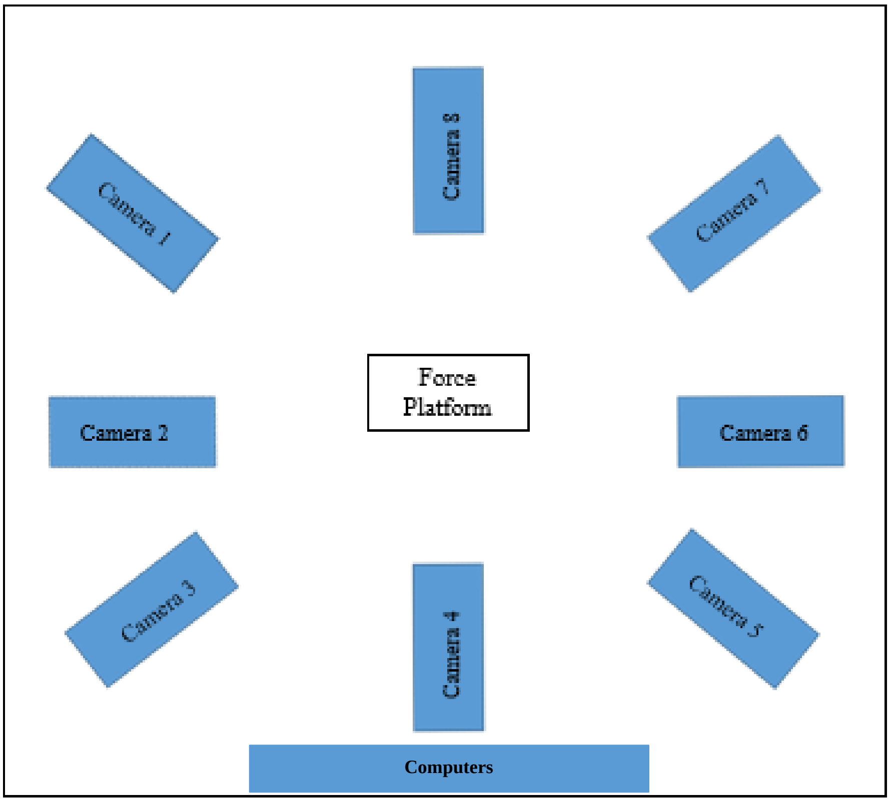


Figure 8. *Experimental set up in the Biomechanics Lab.*

For three separate trials the participants were then asked to perform 85% of their 1RM SN. This percentile was implemented because it is advocated in pertinent literature that technique is shown to stabilise at loads > 80% during Olympic lifting movements (Kipp *et al*., 2012,) but technique may breakdown at loads > 90% (Winchester *et al*., 2009). Therefore, to ensure a true representation of each participant's consistent technique, 85% of 1RM was utilised for the testing protocol. Approximately 2-5 minutes rest between each lift was given to avoid a fatigue effect (Cormie *et al*., 2007). All rest periods were timed with a stopwatch by the researcher.

3.4 Data Collection

An eight-camera three-dimensional Qualisys analysis system, capturing kinematic data at 250Hz (Qualisys Medical, AB, Sweden) was utilized to identify the anatomical markers, barbell markers and cluster plates. Covering the volume of movement, calibration was achieved using an L-Frame and a calibration wand, achieving a standard deviation of <0.5, residuals <0.85 and points > 4000 before data collection commenced (*see **Figure 9***). In conjunction with the kinematic recordings, kinetic data was also captured via a

Kistler piezoelectric force plate no: 9281CA (Kistler instruments Ltd, Alton, Hampshire). The force plate was sampling at 250Hz for 30 seconds for each trial recorded. The kinetic and kinematic data was synchronised through an analogue switch box. For the purpose of this study, it has been assumed there are no asymmetries from left to right hand side of the body. Therefore, the force data captured was produced from each participant's right foot. Each participant was informed they would have a 3,2,1 count down from the researcher, then 30 seconds to step on to the force plate and complete the lift (this time was extended if necessary).

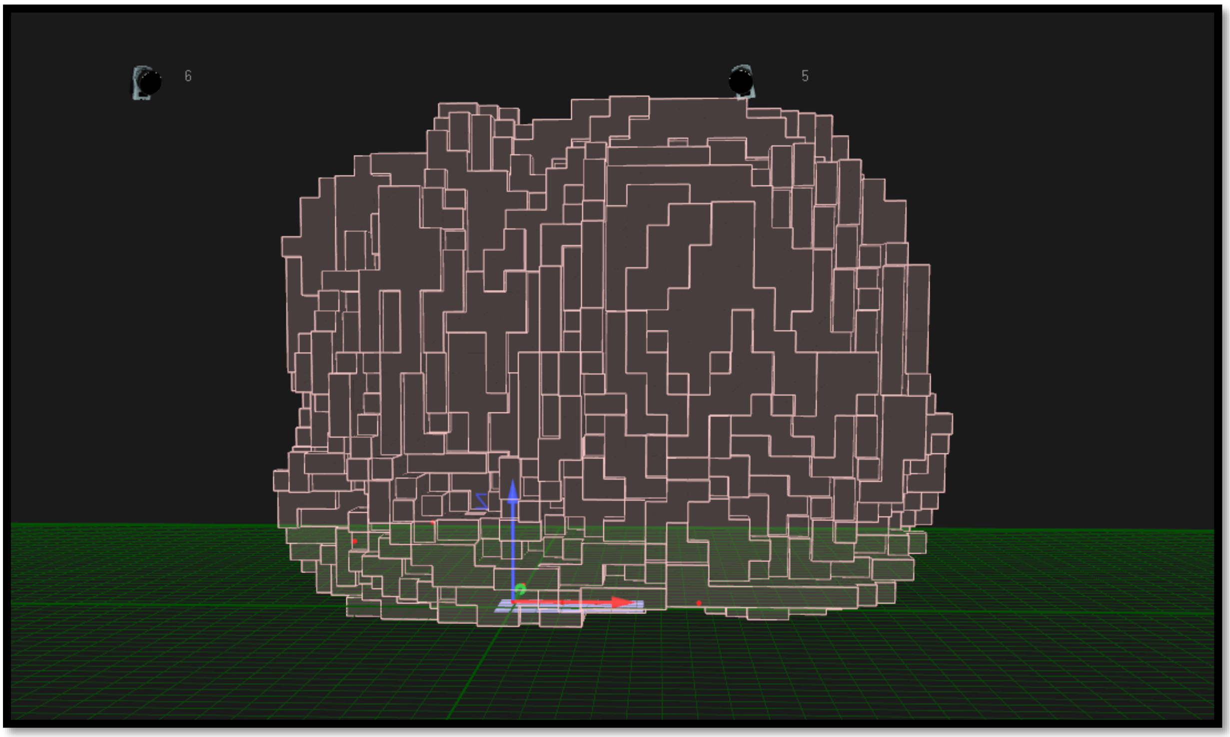


Figure 9*. Visual representation of the calibration volume covered for each trial.*

3.5 Data Processing

<u>3.5.1 QTM</u>

Once the data had been collected all static and dynamic trials were labelled in accordance with the anatomical and barbell marker set and four-point clusters (see **Table 1**). Each recording was then cropped to show the commencement of the lift; the instant the barbell was lifted from the floor, through to the end of the lift; with the barbell disks at arm's length above the participants head.

3.5.2 V3D

The data was exported from QTM and imported into V3D as C3D files. A full body model (s*ee* ***Figure 7***) was created for each participant based on the Calibrated Anatomical Systems Technique (CAST) (Cappozzo et al., 1997). The three dynamic trials for each participant were assigned to their static model and interpolated with a maximum gap fill of 10 frames (Saxby & Robertson., 2010) then filtered with a 4th order Butterworth filter with a cut off frequency of 6 Hz (Saxby & Robertson., 2010).

The SP and the end of the FP were determined from the bar kinematics as follows. Firstly, the bar velocity was calculated using the first derivative of bar motion. Bar velocity was filtered more, to a cut off frequency of 10 Hz, making the data smoother and easier to distinguish the phases of the SN. Following this, an event was created to highlight when the barbell segment moved vertically off the floor by 10mm to determine a standardised SP that could be used for each participant. An event was also created at the end of the FP which was defined as the time when the bar reached knee height. Metric values were then created at the SP: the height of the proximal end of the right femur relative to the vertical to determine absolute hip height at the SP and the angle of ground reaction relative to the horizontal axis. Metric values for the bar position were also taken relative to the horizontal, one at the SP and the other at the end of the FP. To determine maximum horizontal bar displacement from the SP to the FP, the FP position of the bar was subtracted from the SP of the bar, this was calculated using Microsoft Excel (office 16). A positive value meant the bar was moving in a backwards direction from the vertical and a negative value meant the bar was moving in a forward's direction from the vertical (*see **Figure 10***).

Anthropometrics were derived from the V3D model, where right hand side absolute limb lengths was measured from each participant's static trial. The limb lengths were derived from each static trial using the proximal and distal ends of the following segments: femur, forearm, shank, trunk and upper arm using the anatomical markers that would have placed on the participant during the testing protocol (*see **Figure 7***). All following calculations were performed using Microsoft Excel (office 16). Total leg length was calculated by adding femur length and shank length together, along with total arm length, which was calculated by adding forearm and upper arm together. Each participant's absolute limb length values were divided by their standing height to create relative anthropometric values. Absolute hip height was also divided by standing height to create a relative hip height for each participant. Limb length ratios were calculated by dividing one absolute limb length by the coupled absolute limb length, thus creating the following ratios: total leg length to torso, femur to torso, shank to total arm, shank to femur and shank to forearm.

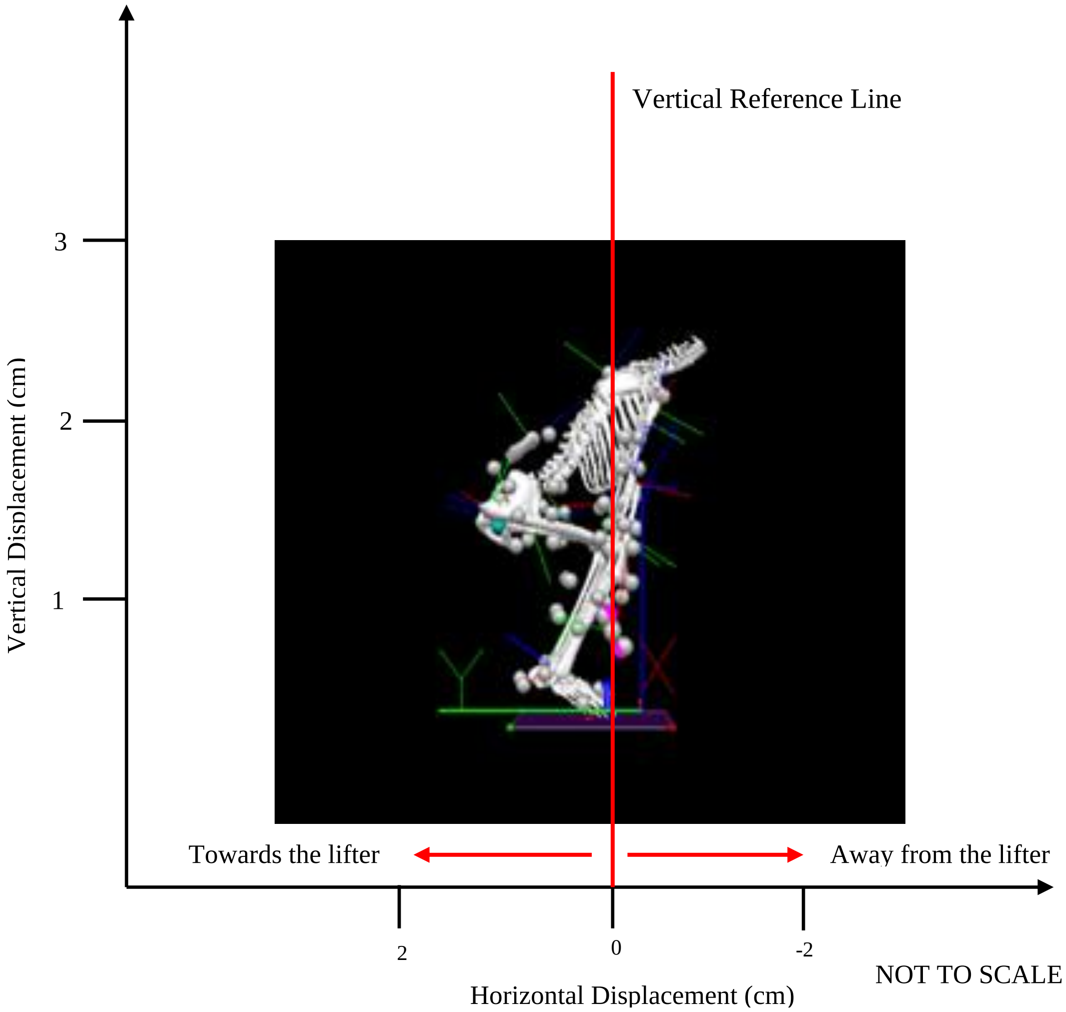


Figure 10*. Visual representation of bar path direction.*

3.6 Statistical analysis

All data was analysed using SPSS statistics 24 software, to analyse the variables following from the aims stated previously. Initial Pearson correlation matrices were performed to test for evidence of collinearity between predictor variables and dependent variables before a stepwise regression analysis could be performed. The first regression analysis utilized absolute hip height at the SP, as the dependent variable, and the anthropometric variables as the predictor variables. This was to investigate which anthropometric measures best predicted the hip height at the SP. The second regression analysis used the resultant ground reaction force angle at the SP as the dependent variable and the anthropometric measures as the predictor variables. This was to investigate which anthropometric measures best predicted the angle of the force vector at the SP. The third regression analysis used maximum horizontal bar displacement and the anthropometric variables as the predictor variables. This was to investigate which anthropometric measures best predicted the horizontal displacement of the barbell from the SP to the FP. Based on the results of the regressions, bivariant correlations were conducted to assess the relationships between anthropometric variables and the outcome measures. Level of significance was set at $p< 0.05$ for both statistical analyses.

Table 2: Table of Variables

<table>
<tr><th>Dependant Variables:
Outcome Measures</th><th>Predictor Variables:
Anthropometric Measures</th></tr>
<tr><td rowspan="3">• Absolute Hip Height at the SP

• Resultant Ground Reaction Force angle at the SP

• Maximum Horizontal Displacement of the barbell from the SP to the FP</td><td>Absolute Anthropometric Lengths
Trunk
Femur
Shank
Total Leg
Forearm
Humerus
Total Arm</td></tr>
<tr><td>Absolute Anthropometric lengths normalised to standing height
Trunk
Femur
Shank
Total Leg
Forearm
Humerus
Total Arm</td></tr>
<tr><td>Absolute Anthropometric Length Ratios
Total Leg Length: Torso
Femur : Torso
Shank : Total Arm
Shank : Femur
Shank : Forearm</td></tr>
</table>

Chapter 4: Results

Anthropometric variables did predict outcome measures (see **Table 3**) of the SN. Including Absolute Femur Length (AFL), relative femur length, relative trunk length and shank to femur ratio (see **Table 4,5,6**). In addition, significant correlations were found between anthropometric variables, Maximum Horizontal Barbell Displacement and absolute hip height.

Table 3. Outcome measures of the SN (Mean ± Standard Deviation)

GRF° (X Axis) (Degrees)	Relative Hip Height (Z Axis) (cm)	Absolute Hip Height (Z Axis) (cm)	MHBD (X Axis) (cm)
0.87 ± 1.78	31.68 ± 3.87	55.37 ± 7.39	1.22 ± 2.80

4.0 Anthropometric Predictors – *Regression analysis*

4.1 HIP HEIGHT AT THE SP

4.1.1 Absolute Hip Height

Participant anthropometric variables (see **Table 4,5,6)** were entered into the regression equation, the model reported AFL to significantly contribute to predicting absolute hip height at the SP of the SN, r^2=0.34, Adjr^2 = 0.31 (F=9.34, p<0.01) (b= 1.201, t=3.10, p<0.01). When Limb length ratios (see **Table 5**) were entered into the regression equation shank to femur ratio was reported to significantly contribute to predicting absolute hip height at the SP of the SN, r^2=0.20, Adjr^2 = 0.16 (F=4.60, p=0.05) (b= -43, t=-2.14, p=0.05). Finally, when anthropometric variables relative to participant height (see **Table 6**) were entered into the regression equation, femur length relative to participant height was reported to significantly contribute to predicting absolute hip height at the SP of the SN, r^2=0.23, Adjr^2 = 0.19 (F=5.30, p=0.03) (b= -2.15, t=-2.30, p=0.03).

4.1.2 Relative Hip Height

Participant anthropometric variables (see **Table 4,5,6**) were entered into the regression equation, the model reported shank to femur ratio to significantly contribute to predicting hip height relative to participant height at the SP of a SN, $r^2=0.22$, $Adjr^2 = 0.18$ ($F=5.19$, $p=0.04$) ($b= -24$, $t= -2.28$, $p=0.04$). When absolute anthropometric variables (see **Table 4**) were entered into the regression equation, the model reported AFL to significantly contribute to predicting hip height relative to participant height at the SP of a SN, $r^2=0.20$, $Adjr^2 = 0.16$ ($F=4.53$, $p=0.05$) ($b= 0.49$, $t=2.13$, $p=0.05$). However, when anthropometric variables relative to participant height (see **Table 6**) were entered into the regression equation none of the variables predicted relative hip height.

4.2 MAXIMUM HORIZONTAL BARBELL DISPLACEMENT (MHBD)

The regression model found no significant contribution from any anthropometric variables in predicting MHBD from the SP to the FP. Absolute hip height was entered into the regression equation; the model reported that absolute hip height significantly contributed to horizontal barbell displacement from the SP to the FP, $r^2=0.37$, $Adjr^2 = 0.34$ ($F=10.70$, $p<0.01$) ($b= -0.23$, $t=2.13$, $p<0.01$).

4.3 GROUND REACTION FORCE VECTOR ANGLE (GRF°) AT THE SP

Participant anthropometric variables (see **Table 4,5,6**) were entered into the regression equation and three predictor variables were reported in the regression model $r^2=0.77$, $Adjr^2 = 0.73$ ($F=5.33$, $p=0.04$) ($b= 68.86$, $t= -5.57$, $p<0.001$). Model one reported femur length, relative to participant height, to significantly contribute the most to the prediction equation $r^2=0.45$, $Adjr^2 = 0.41$ ($F=14.42$, $p<0.01$) ($b= -99.54$, $t= -9.93$, $p<0.01$). Model two reported trunk length, relative to participant height, to significantly contribute, the second most to the prediction equation $r^2=0.69$, $Adjr^2 = 0.26$ ($F=13.67$, $p<0.01$) ($b= -115.45$, $t= -4.74$, $p<0.001$). Model three reported shank to femur ratio to significantly contribute, the third most to predicting GRF° at the SP of the SN $r^2=0.77$, $Adjr^2 = 0.07$ ($F=5.33$, $p=0.04$) ($b= -9.24$, $t= -2.31$, $p<0.001$). No other variables were entered into the regression model.

Table 4. Absolute Anthropometric Lengths (cm) (Mean ± Standard Deviation)

Trunk	Femur	Shank	Total Leg	Forearm	Humerus	Total Arm
43.51 ± 2.63	42.85 ± 3.60	40.28 ± 2.38	83.13 ± 5.17	25.72 ± 01.40	27.70 ± 1.52	53.42 ± 2.51

Table 5. Absolute Anthropometric Length Ratios (1:2) (Mean ± Standard Deviation)

Total Leg Length: Torso	Femur: Torso	Shank: Total Arm	Shank: Femur	Shank: Forearm
1.91 ± 0.13	0.99 ± 0.10	0.75 ± 0.03	0.95 ± 0.08	1.57 ± 0.06

Table 6. Absolute Anthropometric lengths (cm) normalised to standing height (cm) (Mean ± Standard Deviation)

Standing Height	Trunk	Femur	Shank	Total Leg	Forearm	Humerus	Total Arm
173.18 ± 6.50	25.14 ± 1.10	24.73 ± 1.63	23.25 ± 0.80	47.00 ± 1.74	14.85 ± 0.50	16.00 ± 0.78	30.85 ± 1.00

4.4 Relationships between MHBD, AFL and absolute hip height.

A significant negative relationship was found between absolute hip height and MHBD r= -0.61 R^2=0.37 TEE=6.02, p <0.01, (*see* ***Figure 11***) showing that absolute hip height accounts for 37% of the variation for MHBD from the SP to the FP during a SN. A significant positive relationship was found between AFL and absolute hip height r= 0.58 R^2= 0.34 TEE=6.16, p = 0.01 34% (*see* ***Figure 12***) showing that AFL accounts for 34% of the variation in absolute hip height at the SN SP. A negative relationship was found between AFL and MHBD r= -0.434, R^2 = 0.19 TEE=3.33, p =0.06 (*see* ***Figure 13***) showing that AFL accounts for 18.7% of the variation for MHBD from the SP to the FP during a SN.

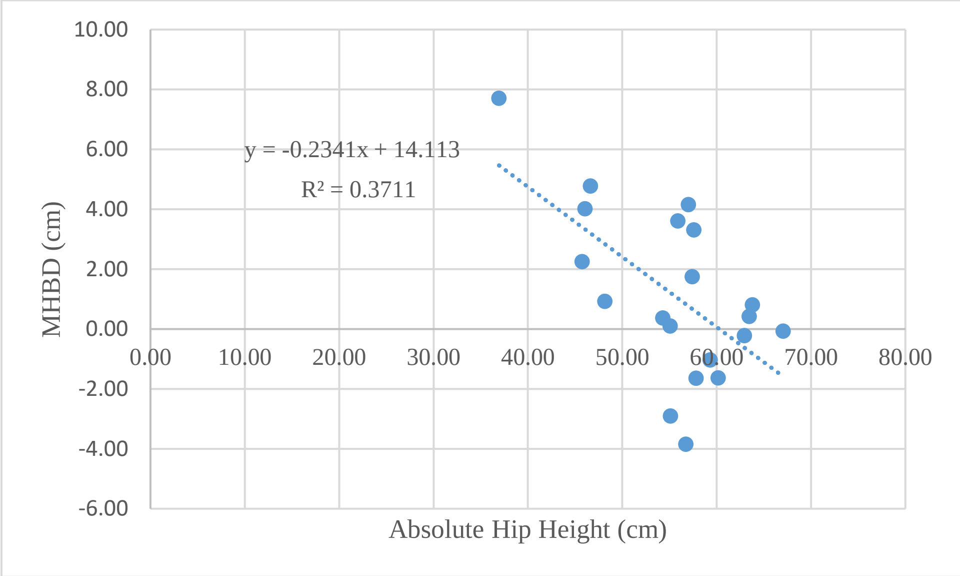


Figure 11. *Absolute Hip Height and MHBD Relationship.*

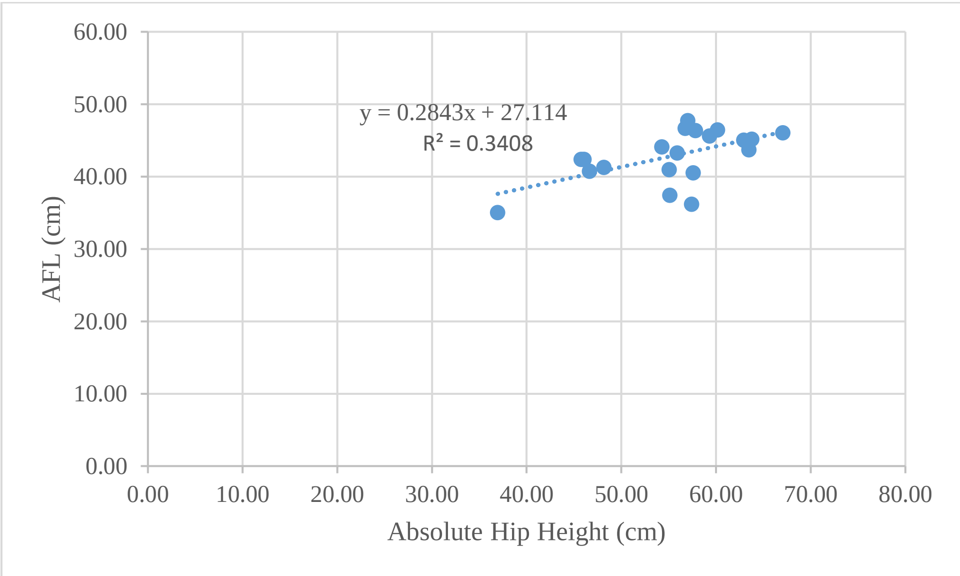


Figure 12*. AFL and Absolute Hip Height Relationship.*

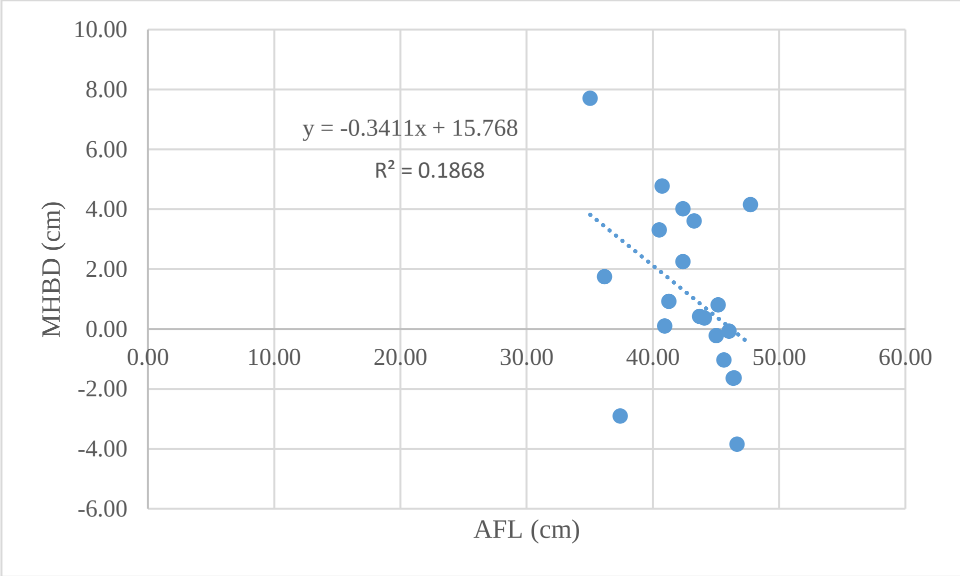


Figure 13. *AFL and MHDB Relationship*

Chapter 5: Discussion

The primary objective of this study was to inspect the relationship between individual anthropometric variables and the habitual SP adopted by experienced male weightlifters. A further aim was to investigate how the adopted SP influenced outcome measures of the SN lift. The three main aims were; 1) identify which anthropometric variables predict the SP of the SN, 2) identify which anthropometric variables predict the angle of the force vector during the FP, 3) identify which anthropometric variables predict the direction of the bar path from the SP to the end of the FP. To the researcher's knowledge this was the first study to explore combined relationships between anthropometrics, adopted hip height at the SP, kinetics and barbell kinematics in experienced participants.

The anthropometric characteristics analysed were: absolute body segment lengths (see **Table 4**) absolute limb length ratios (see **Table 5**) and body segment length normalised to standing height (see **Table 6**). AFL and shank to femur ratio were found to be significant predictors of hip height, relative to the floor, at the SP of the SN. Relative femur length, relative trunk length and shank to femur ratio were found to be significant predictors of the GRF° at the SP of the SN. No anthropometric variables were found to be significant predictors of MHBD.

5.1 Hip Height at the SP

The SN SP for each participant was determined by their absolute hip height relative to the floor. The results found that AFL was the highest significant predictor of absolute hip height. Furthermore, a positive correlation was found between absolute hip height and AFL which indicated that as absolute hip height increased, AFL increased also. Upon further analysis, a difference was found when absolute hip height was divided by femur length, demonstrating that participants with a shorter femur had a lower hip height and participants with a longer femur had a higher hip height. This relationship indicates that the longer a lifters femur is, the higher the adopted absolute hip height is at the SP of a SN, ***Figure 14*** represents the spectrum of femur lengths and their associated hip height. These results indicate the importance of considering femur length when prescribing an individual's hip height when aiming to achieve an optimal SP.

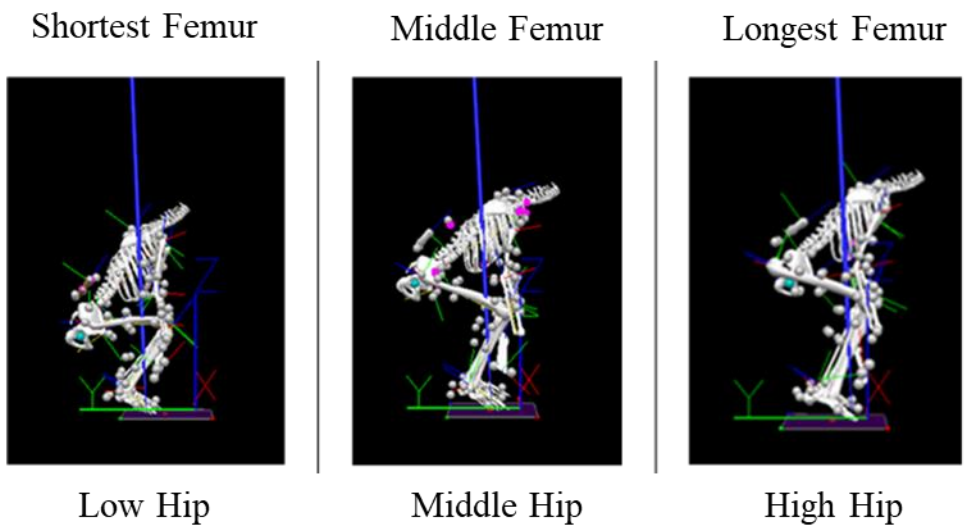


Figure 14*. SP Spectrum. Participants SN SP representing the relationship between AFL and absolute hip height. These images represent the skeletal model in V3D, where the blue line represents the GRF°.*

It can be posited that a lifter with a longer femur would require a higher hip position. If the long-femured lifter were to adopt a lower hip position, it would require increased knee bend, this would in turn decrease torso lean. This is in agreement with the observations from Aita. (2017). This would place the lifter with a longer femur in a more disadvantageous position due to the need for additional knee bend, substantially increasing the lever arm at the knee. Consequently, this would place a higher demand on the quadriceps (Zajac, 2002) and the decreased torso lean would reduce the lever arm at the hips (Ho *et al.*, 2011). This would also have implications for the ability of the lower back and hip musculature to maximise their leverages and optimising force production would be diminished (DeWeese *et al*., 2012). These points provide evidence as to why shank to femur ratio was the highest predictor of relative hip height. Additionally, shank to femur ratio was also the highest predictor of absolute hip height, but only when the regression was exclusively focused on limb length ratios. The high predictions found are likely due to the shank to femur ratio influencing how much knee bend would be required to achieve the optimal SP in the SN. This indicates the importance limb lengths have on manipulating the interaction between knee angle, hip height and torso lean, for an athlete to obtain their optimal SP. Further investigation would be beneficial to accurately encompass how these joint interactions, relative to individual anthropometries characteristics, affect their SP. How this then influences outcome measures would further enhance the coaches understanding of how an individual's characteristics affects Olympic weightlifting performance.

5.2 Hip height and Bar Path

MHBD was determined as the point from the SP of the SN to the end of the FP. Absolute hip height was found to significantly predict barbell trajectory during this phase of the SN. Upon further analysis, when MHBD was divided by hip height, despite there being an overall predominance of backwards bar paths, there was an indication that those with a higher hip SP produced less backwards movement than those with a lower hip SP. It is generally accepted that a bar path travelling forwards, away from the lifter, from the SP to the FP is undesirable and is considered less efficient (Stone *et al*., 1998; Gourgoulis *et al*., 2000; Hadi *et al*., 2012; Musser *et al*., 2014). Considering this, the participants in this study had SP's that facilitated this desired bar path between the SP and the FP. ***Figure 15*** shows that, despite the differences in hip height and femur length, the bar paths are all moving backwards, towards the lifters.

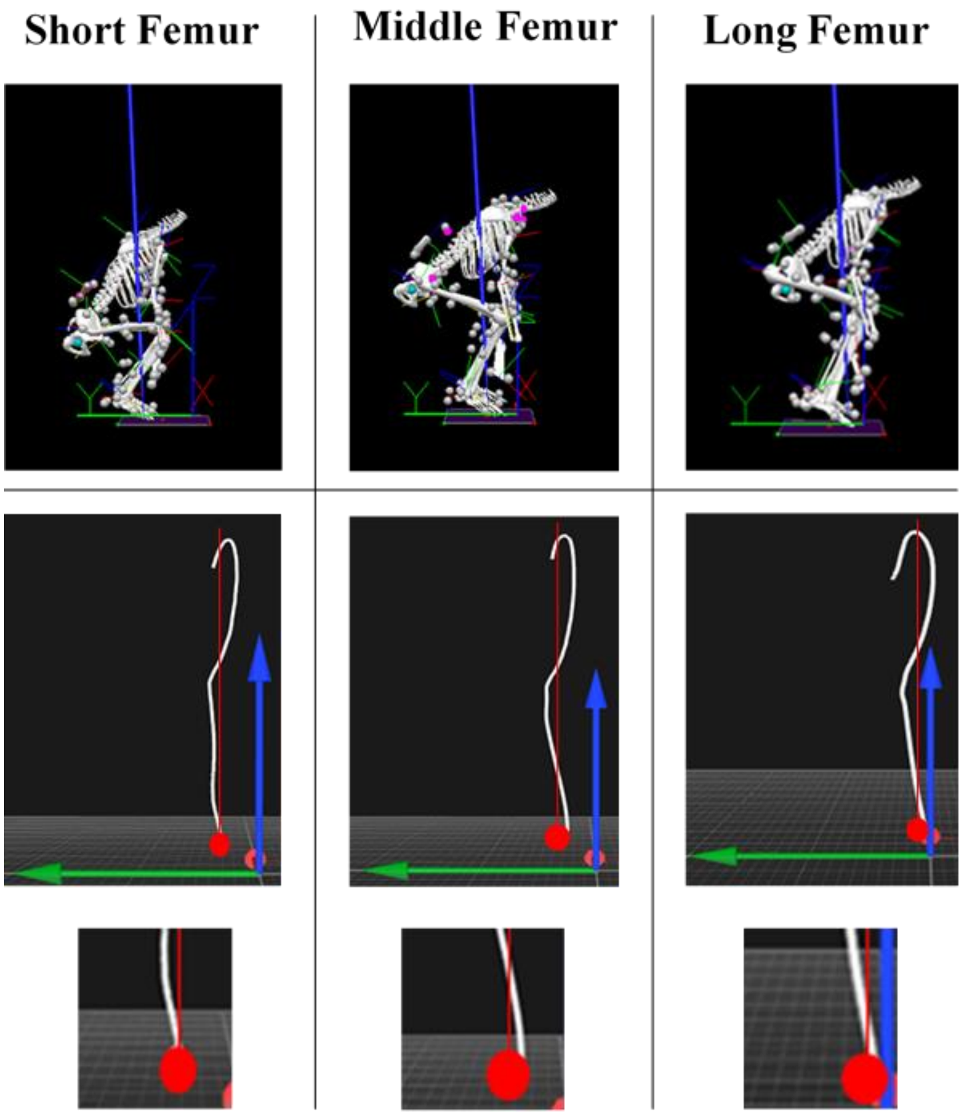


Figure 15*. Visual representation of how AFL can influence absolute hip height whilst still achieving the same backwards bar path. Top images represent the skeletal model in V3D, where the blue line represents the GRF°. Middle and bottom images represent the barbell trajectories in QTM, where the red line represents the vertical reference line.*

Although no anthropometric variables were significant predictors of MHBD, it could be suggested that an indirect relationship exists between AFL, shank to femur ratio and MHBD. This is due to AFL and shank to femur ratio being significant predictors of absolute hip height, and absolute hip height being the primary significant predictor of MHBD. As previously discussed, the femur length of a lifter influences the height of the hips and, in-turn, impacts how much knee bend is required at the SP of a SN. Therefore, if all other coaching points are considered and optimised (see SP: pages 17-20), if a lifter with a comparatively longer femur was to adopt a lower hip position, this would result in the knees being over the bar because of the larger knee bend. In this instance the knees would have to come back quickly (extend), potentially causing the shoulders and torso to drop forward. Or the bar would have to go around the knees, causing a forward barbell trajectory between the SP and the FP. This could suggest that if a lifter has a forward moving bar path during the FP of their SN and has a comparatively longer femur; increasing the height of their hips may be conducive to achieving the desirable bar path. Thereby positively impacting their SN performance (Ho *et al.*, 2014 & Musser *et al.*, 2014). ***Figure 16*** demonstrates how femur length can influence the direction of the bar path from the SP to the FP when lifters adopt similar hip heights.

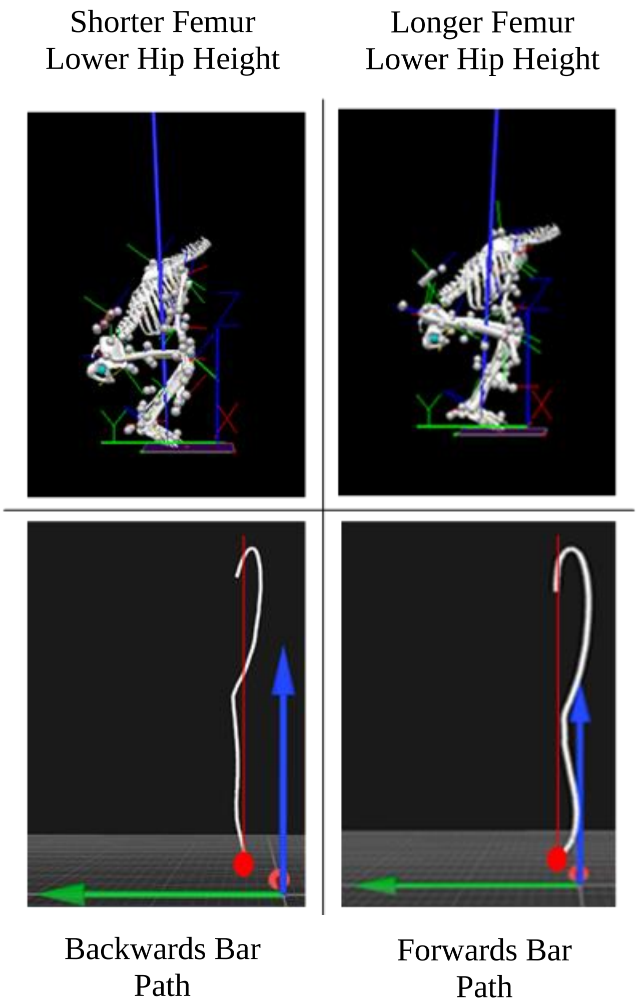


Figure 16. *Visual representation of how femur length can affect bar path between participants when Absolute Hip Heights are similar. Top images represent the skeletal model in V3D, where the blue line represents the GRF°. Bottom images represents the barbell trajectory in QTM, where the red line represents the vertical reference line.*

Conversely, a lifters flexibility and hip structure should also be considered (Stone *et al*., 2006) when adopting a SP. Hip structure refers to the way the femur sits in the acetabulum, which can vary between individuals. Some are shallow, whilst others are deep, some sit more anteriorly, whilst others are positioned more posteriorly. All of which will affect how much range of motion is available at the hip joint, thus influencing the amount of mobility an individual possesses. Furthermore, the length and angle of the femur neck, where it meets the pelvis varies between individual's and can also affect how much range of motion can be achieved at the hip joint. For example, an individual with a longer femur neck with a larger angle of inclination will have a larger external rotation capacity on a skeletal level (Byrne *et al*., 2010). The required torso angle, knee bend and hip height at the SP is impacted by the amount of external rotation available at the hip (see knee flare: page 20) (Everett, 2009). The more external rotation a lifter can achieve, the less knee bend is required at the SP (Everett, 2009 & Aita, 2017). Therefore, it seems that more knee flare may facilitate a backwards bar path, even for lifters with comparatively longer femurs. Further research is needed in the topic of mobility and how it impacts a lifters SP in the SN. However, it is clear that despite femur length having been highlighted to be a significant variable, achieving an optimal SP is highly multifactorial.

5.3 Forward and Backwards Barbell Trajectory

The MHBD results of the participants were categorised into forwards and backwards bar paths. It was demonstrated that the participants with a forwards bar path generally adopted a relatively higher hip height at the SP, comparatively to the participants with a backwards bar path. The results showed that 5 out of the 7 participants (71%) with a forwards bar path adopted a higher hip height. Whilst 9 out of 13 participants (69%) with a backwards bar path adopted a lower hip height. This partly explains why absolute hip height was the most significant predictor of MHBD. This also explains why a significantly moderate, negative correlation was found between MHBD and absolute hip height. Which demonstrates that the higher the adopted hip position at the SP, the more the bar travels forwards and away from the lifter during the FP.

Furthermore, anthropometric variables were not found to be significant predictors of MHBD. However, the data marginally showed that participants with a forwards bar path tended to have comparatively longer femurs than those who displayed a backwards bar path. However, overall the femur lengths of both bar path trajectories were similar. This result mirrors that of Musser *et al*. (2014), who also found no significant correlations between anthropometric variables and horizontal barbell displacement from SP to FP of the SN. In addition, AFL was found to correlate with MHBD, this result indicates that as AFL increased, the barbell travels forwards away from the lifter. Although, this relationship was weak it was approaching statistical significance where AFL accounted for 18.7% of the variance in MHDB, suggesting that AFL plays a very small role in the direction of the bar path. Musser *et al.* (2014) also found a relationship between the lower limb and direction of the bar path. Those findings were contradictory to that of this study, which found that as the length of the lower limb decreased, the amount the bar moved towards the lifters decreased. However, the relationship reported by Musser *et al*. (2014) was only found in one of the pooled weight classes, as opposed to the current study where all participants were grouped. It is important to note that the current study and the study by Musser *et al*. (2014) described the same portion of the barbell trajectory but defined them differently. As indicated by ***Figure 5*** (DX1), Musser and colleagues define the end of the FP as the point where the bar reaches the lifters' hip crease *(see **Figure 2**.D)* whereas this study refers to the end of the FP as the point at which the bar reaches the lifters' knees (*see **Figure 2**.B*). Therefore, although there are similarities between these studies results, they cannot be directly compared due to the discrepancy in the measurements used to define the phases of the lift.

An interesting study by Chen & Chiu. (2011) assessed lifter and bar performance by assessing the internal angle formed in the sagittal plane between the barbell, 7th cervical spinous process and the subsequent projection vector to the hip joint. This was referred to as the BCH angle. The authors found that when divided by barbell trajectory (forwards and backwards), the BCH angle at the PP and the maximum forward barbell position during the SPL, are seen to be smaller in the backwards bar path group compared to the forwards. This study went on to suggest that smaller BCH angles (keeping the bar closer to the body) results in a more successful SN technique. In addition, the phase analysis breakdown indicates that the BCH angle between the two barbell trajectory groups are the same at both the SP and the FP, before the significant discrepancy between the two groups occurs in the later phases of the pull. Showing that even when barbell-lifter positioning at the initial stages of the SN are the same, individual execution and technique can differ at any stage of the lift which could be as a result of individual characteristics. Whilst it is useful to compare to this study, the work by Chen & Chiu (2011). is considered too simplistic to provide any further meaningful insights into how anthropometrics affect lifter and bar kinematics because of the focus on just one measurement angle.

5.4 GRF°

Relative femur length, relative trunk length and shank to femur ratio were the anthropometric variables that significantly predicted GRF° at the SP of the SN. Corresponding with the results of other anthropometric literature within the strength sport field; Musser *et al*. (2014) found thigh and trunk variables to significantly correlate with performance in experienced weightlifters. Absolute shank length and relative torso length have also been highlighted as performance markers in powerlifters (Cholewa *et al*., 2019). Furthermore, it is commonly understood that the more elite Olympic weightlifters possess an anthropometric profile which includes proportionately shorter femurs and proportionately longer torsos relative to their height (Stone *et al*., 2006; Keogh *et al*., 2009; Musser *et al*., 2014). Therefore, if all other coaching points are considered and optimised (see SP: pages 17-20), how long an individual's femur is and how tall they are will dictate how much torso lean is required when setting up at the bar. How much torso lean also establishes how much knee bend is necessary which is then determined by the relative shank length to the individual's femur length. However, the amount of available ankle range of motion can affect the amount of knee bend an individual can achieve (Myer *et al*., 2014), which should be a factor for coaches to consider. All of which will have an impact on which direction they will produce force into the floor. A lifter with a relatively short femur and a longer torso comparative to their height may be more likely to have a low hip height and more upright torso position. The shank to femur ratio of the lifter will aid in determining the appropriate hip height but will also create an appropriate amount of knee bend, that places the lifter in a SP that allows them to push into the ground with their mid foot. Thus, producing a positive force angle, which results in a backwards barbell trajectory from SP to the FP. This explains why femur length, trunk length (relative to an individual's height) and shank to femur ratio predicts the direction of force at the SP, because they are all connected and the length of one segment directly impacts the position of the other segment. Each segment therefore has to be in optimal position to ensure force is being produced from the midfoot of the lifter to create a positive force angle.

The results of this study indicate that anthropometric variables are important to consider when working towards obtaining an optimal SP that allows an individual to produce force in the direction that maximises performance. Synchronising the upper and lower body to optimise mechanical levers will have a direct impact on barbell kinematics. A negative force angle will create a forward's barbell trajectory, whilst a positive force angle will create a backwards barbell trajectory as shown in ***Figure 16***. As such, it is extremely important that the coach considers the differences in anthropometrics to ensure that each lifter adopts a SP that enables a slightly rearward resultant GRF°.

5.5 Case Study

It was observed that the participant who had the lowest hips at the SP also had the shortest femur, as well as having the largest backwards bar path (*see **Figure 15***). Furthermore, the participant with the largest forward bar path had a comparatively longer femur and a lower hip height SP (*see **Figure 16***). This participants data showed that between their 1st and 3rd attempt their hips had risen and resulted in a more forwards moving bar path (*see **Figure 17***). As well as the bar path, another difference between the 1st and 3rd trial of this participant was their increased torso lean and shoulders relative to the stationary barbell. It can be assumed based on the SP of this participant, that the barbell has remained in the same position relative to their foot due to their torso being further over the bar in the 3rd attempt. This would have shifted the lifters weight further on to their toes, which reduces the ability to push into the ground through the middle of the foot. Forcing the lifter to apply force negatively, as shown by the blue line in the top row of ***Figure 17***. Additionally, because of the increased torso angle this would have shifted the lifters centre of mass further forward meaning the bar had to move forwards, combining the centre of masses of the bar and the lifter to create a barbell-lifter system. This combination results in the bar path going further forward which is not a desirable barbell trajectory and is more likely to lead to an unsuccessful lift. This coincides with the conclusion of Gourgoulis *et al.* (2009) who found that proper direction of force application on to the barbell, from SP to FP was the only significant difference between successful and unsuccessful attempts of the SN in high- level male weightlifters. Furthermore, it is evident from this case study that an optimal SP is more than just the height of hips, though it is an integral part. This agrees with Ho *et al.*, (2011), who identified hip joint angle as a key feature to increasing success of a SN lift. However, hip height, knee bend and torso lean all have to be considered to create an optimal SP. This case study demonstrates the importance of the system working as a whole and how one joint has a direct impact on another. In order for force to be transferred effectively through the kinetic chain, body segments must be arranged so that muscle length-tension relationships are optimised and joint torque can be maximised.

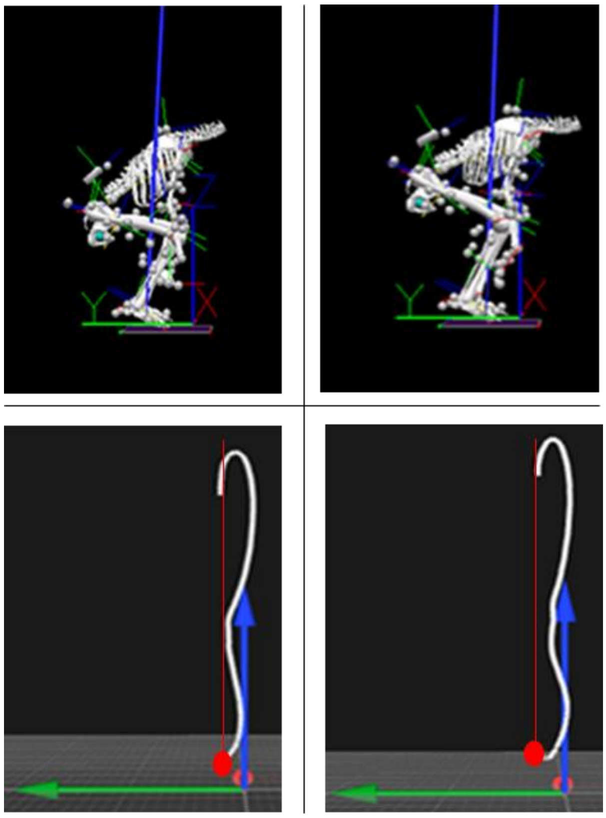


Figure 17. *Case study. Representing 2 trials from the same participant. Left Trial 1, Right trial 3. Top images represent the skeletal model in V3D, where the blue line represents the GRF°. Bottom images represents the barbell trajectory in QTM, where red line represents the vertical reference line.*

5.6 Limitations and Future Research Directions

Future research in Olympic weightlifting should focus on longitudinal case studies investigating technique development and how performance is affected, from novice to competent lifters. This would aid the knowledge of weightlifting coaches, athletes and strength and conditioning practitioners to inform the process of technique optimisation to maximise performance on an individual basis. Further investigation is warranted into how joint interactions relative to an individual's anthropometric characteristics affects their SP, especially in relation to their torso angle relative to the horizontal axis. Additional research should also be dedicated to examining the effects of a lifters mobility and the position that they are able to adopt at the SP and during each phase of the SN. How these factors then influences outcome measures would further enhance the coaches understanding of how an individual's characteristics affects Olympic weightlifting performance.

The results of this study are only from one singular SN lift session, with just 3 lifts worth of data being collected, this is a small recording of each lifters SN technique. Therefore, from these 3 single repetitions it is not guaranteed that each lifter is adopting their preferred and repeatable SP during these trials. Therefore, longitudinal research gathering a larger pool of data to investigate long term technique development for individuals would give insight in athletes developing consistent, repeatable SN techniques.

The small sample size of this study combined with the criterion variables applied during participant recruitment limits the results of this study to predict SP's from anthropometrics, to a specific population. Meaning the results are unable to be projected onto other population groups such as females and lifters in heavier weight classes. Thus, this study recommends further research that combines anthropometrics with bar path kinematics and phasic analysis of the barbell-lifter system to be done across a variety of population groups.

Anatomical landmark identification using the CAST technique (Cappozzo, 1995) is considered the gold standard for 3D kinematic analysis (Richards & Thewlis, 2008; Sinclair et al., 2012) and has been defined as reliable by Sinclair et al., (2012) using a test- retest study design. Despite this, a specific reliability test for this study testing the accuracy or repeatable marker placement for the researcher was not conducted. However, prior to undertaking this study the researcher had plentiful experience palpating and positioning anatomical markers on over 100 participants, from which data was collected before being used in other published research articles (Butters, Sinclair, 2018,2019).

5.7 Conclusion

AFL has been identified as the most significant predictor of an individual's absolute hip height at the SP of the SN, with further analysis showing absolute hip height as a significant predictor of MHBD from the SP to the FP. Furthermore, it was identified that participants of different femur lengths were able to achieve similar barbell trajectories regardless of hip height. The results of this study show that the longer a lifters femur is the higher their hip height should be at the SP of the SN. However, further analysis revealed participants who executed a forward horizontal bar path predominantly adopted a higher hip position at the SP, comparative to the participants executing a backwards horizontal bar path who adopted a lower hip position. A case study demonstrated that if a lifter does have a long femur, although a higher hip is necessary, there should not be a large increase in torso inclination that causes the shoulders to be positioned excessively far over the bar. There should also be a consideration for bar position relative to the lifter because if the bar is too close this will also cause the same improper shoulder position over the bar, causing the lifters centre of mass to be too far forwards. An increased torso angle has a higher chance of resulting in an increased forward horizontal bar path. Finally, it was found that relative femur length, relative trunk length and shank to femur ratio were all significant predictors of GRF°. Where it was identified that applying force into the ground at the SP at a positive angle allows for a desirable vertical/backwards bar path showing the importance of the kinetic chain being synchronised. Based on these results it can be concluded that a lifters femur length is of high consideration when prescribing an optimal SP for the SN lift. However, a combined approach that considers the length of a lifters femur in conjunction with how the femur effects the entire barbell-lifter system is desirable.

5.8 Practical Applications

The results of this study are of importance to both weightlifting coaches and athletes, as well as strength and conditioning practitioners. This study provides direction in addition to the subjective observations that occur during technique analysis and can aid in determining an individual's optimal SP. Throughout Olympic lifting literature and coaching practice it is becoming widely accepted that anthropometric characteristics predominately determines an individual's "optimal" SP in the SN. However, a gold standard approach is still insinuated by technique descriptions being built of sweeping statements such as "shoulders in line with the bar", "hips higher than knee joint centre and shoulders above hip joint centre", "middle of the foot in line with the stationary barbell," (Everett, 2009; Ho et al., 2014; Deweese, 2012; Musser *et al.*, 2014; Turner & Comfort, 2017). Whilst it is beneficial to have guidelines for achieving a "good" SP, especially to a novice lifter, information on how an individual can find their optimal SP by considering their body proportions and limb lengths would also be beneficial. As an example, AFL as an anthropometric measurement has been reported to be a significant predictor of an individual's hip height at the SP of the SN, this should be used as a guideline to inform rather than dictate technique and SP prescription.

Furthermore, to optimise technique analysis, individual anthropometric characteristics should be considered in conjunction with the complex interaction between lower extremity joints, the spinal column and the upper body segments. Manipulating these anthropometric variables should ultimately allow the coach and lifter to arrive at a SP that ensures the lifter is applying force into the ground at an angle of approximately 1.5-2°. This will result in the most optimal bar path and thus increase the probability that the lift is successful. The advice from the researcher to fellow coaches and strength and conditioning practitioners would be that it is important to consider how the femur length can influence the overall SP of the lifter, not just that the length of the femur may influence the hip height.

To conclude, the conscientious coach should initially spend time familiarising him/herself with lifting techniques and postures that minimises horizontal barbell displacement, especially forward deviations from a stationary bar starting point. Building an ideal silhouette posture in their minds eye overtime will naturally build to give them a starting point with each new athlete they encounter. Then according to the lifter's anthropometrics, with large consideration primarily for femur length, as well as relative trunk length and shank to femur ratio, the coach should work with the lifter in achieving their ideal SP. Each lifter should be treated as an individual case study rather than applying a 'one-size-fits-all' approach.

Appendices

Appendix A: Ethical Approval

University of Central Lancashire

13 August 2018

Chris Edmundson / Bobbie Butters
School of Sport and Wellbeing
University of Central Lancashire

Dear Chris / Bobbie

Re: STEMH Ethics Committee Application
Unique Reference Number: **STEMH 905**
The STEMH ethics committee has granted approval of your proposal application 'Does the start position based on anthropometrics influence the outcome of the Snatch? '. Approval is granted up to the end of project date*.
It is your responsibility to ensure that
• the project is carried out in line with the information provided in the forms you have submitted
• you regularly re-consider the ethical issues that may be raised in generating and analysing your data
• any proposed amendments/changes to the project are raised with, and approved, by Committee
• you notify EthicsInfo@uclan.ac.uk if the end date changes or the project does not start
• serious adverse events that occur from the project are reported to Committee
• a closure report is submitted to complete the ethics governance procedures (Existing paperwork can be used for this purposes e.g. funder's end of grant report; abstract for student award or NRES final report. If none of these are available use e-Ethics Closure Report Proforma).

Yours sincerely

Julie Cook
Deputy Vice-Chair
STEMH Ethics Committee
* for research degree students this will be the final lapse date
NB - Ethical approval is contingent on any health and safety checklists having been completed and necessary approvals gained as a result.

Appendix B: Extension Approval

Research Student Registry
University of Central Lancashire
Preston PR1 2HE
Telephone; +44 1772 895085
www.uclan.ac.uk

30th January 2019

Bobbie Butters
G20625652

Sent out by email

Dear Bobbie

Application for Extension of Research Degree Programme

I am pleased to advise you that your application to extend your research degree programme has been approved.

An extension of 2 months and 14 days was approved. Therefore, your new deadlines dates are as follows:

Expected Completion date: 14th December 2019
Latest Lapse date: 14th December 2020

The School has agreed to pay your tuition fees to cover this period of extension. An adjustment to your fees of £525.00 has been made in this academic year. Therefore, your tuition fees for 201819 have been amended to £1,155.00.

If appropriate, the Director of Studies is requested to notify any external funding body (for example, research council) of the extended end date. Please refer to the Tuition Fee Policy.

Yours sincerely

Clare Wiggans

Clare Wiggans
Senior Administrative Officer (Research)
Research Student Registry
Harris Building, room 104
Tel: 01772 894647
Email: help4researchstudent@uclan.ac.uk

Copies: Chris Edmundson - Director of Studies
Bojlul Bahar - RDT

Appendix C: Participation Information Sheet

Participation Information Sheet

Does the start position based on anthropometrics influence the outcome of the Snatch?

You have been invited to participate in the testing as part of on-going sport and exercise science support for athletes, exercisers and general populations. This is led by the University of Central Lancashire, Centre for Applied Sport and Exercise Sciences, under the guidance of Director of Studies; Dr Chris Edmundson. All communications should be directed towards the lead tester in the first instance.

This practical lab-based session asks you to perform The Snatch Olympic lift at 85% of your current one repetition max at varied percentages of your 1RM. This form provides basic information regarding testing protocols and also asks you to confirm your understanding of the information and agreement of taking part. Such information and agreement is referred to as informed consent.

Purpose of this study

It is understood throughout research that individual anthropometrics play a role in Olympic lifting and recently it has become evident that limb length ratios may influence the type of barbell trajectory created by the lifter. This study aims to extend current knowledge and aid fellow scientists, coaches and athletes in understanding the snatch lift, in more individualistic terms.

The Testing will involve:

- Completing a Physical Activity Readiness Questionnaire (PAR-Q+). This is a simple seven item questionnaire to assess any potentially medical problems that would preclude testing. It is important that these forms are completed and handed to the tester. If any issues arise from completing these forms, then you will not be allowed to undertake the testing until we receive medical clearance from your physician.
- Questions about current lifting capability including 1 RM?
- You will be asked to perform 3 single attempts snatch lifts at 85% of your current pre-determined one repetition maximum. The Test will terminate once you have completed the 3 trials This test could potentially be quite physically demanding as you will be performing a highly complex and dynamics movement at a moderate intensity. You will be asked to carry out a progressive warm up before attempting the lifts and you will be given sufficient rest times between attempts. You can stop the experiment at any time with no reason for doing so if you do not wish to continue.

- Reflective markers will be placed on your body on joint centres and limb, trunk and arm segments in order to measure your joint angles and movement throughout the lift.

Before any lifting is to take place, you will be asked to complete an efficient and appropriate warm up which includes body mobilisation, pulse raising and movement specific drills. This will be the warm up protocol that you would do on a normal lifting day and will be aided by the researcher.

It is important to note that you can remove yourself from the testing at any point without prejudice. If you are feel unwell or you experience any pain do not feel obliged to push yourself and please inform the tester if this is the case.

If you agree to undertake this testing, please sign the section below. It is a requirement that you sign the form.

Risks of taking part

Due to the nature and high demand of this activity there is a small risk of potential injury including; muscle and ligament strains. These are deemed to be small risks as you will be instructed through a thorough warm up and appropriate activation drills. Furthermore, a requirement for this study was to be experienced in the Olympic lifts over the past 2 years therefore the activity required for this study should be similar to your current training. However., if you do feel any pain during the data collection you should stop immediately. Furthermore, if an injury occurs as a result of this activity; Uclan has a physiotherapy clinic based on campus that you can access at http://www.uclanphysioclinic.co.uk/.

All communications should be made to,
Bobbie Butters
MSc (by research) Student
University of Central Lancashire
Preston
PR1 2HE
Bbutters@uclan.ac.uk

Appendix D: Participant Consent form

Consent to testing

The nature, demands and the risks associated with the project have been explained to me. I knowingly accept the risks involved and agree to participate in the above named study. I understand that I may withdraw my consent and discontinue participation at any time without having to give an explanation. I understand that performance or completion / non-completion of this testing will not have any bearing on current or future coaching sessions and is being collected purely to enhance knowledge on relationships between anthropometrics and lifting performance.
I understand that all data that is produced and videos (of the markers) that are recorded will be anonymised (i.e. given a number as an identifier). I understand that the anonymous data will be used in publications and presentations about the project.

Name of participant (print)……………………

Signed………………… Date ………….

I certify that I have explained to the above individual the nature, purpose and possible risks associated with participation in this research study, have answered any questions that have been raised, and have witnessed the above signature.

Name of investigator (print)……………………

Signed………………… Date ...……….

Appendix E: Risk Assessment

SENS RISK ASSESSMENT FORM
(for Projects, Research, Consultancy & Testing)

Use this form to risk-assess:

- *Off-campus work (research, fieldwork, educational visits etc)*
- *All lab / classroom / sports-hall based activities involving medium/high risk procedures or use of specialist equipment*
- *All project work, research, consultancy and testing of athletes or equipment*

This form should be completed by the investigator and verified by a member of SENS staff, in conjunction with a qualified or otherwise competent person (normally a technician or Faculty HSE officer). Completed forms must be countersigned by the Head of School or the Chair of the School Health & Safety Committee.

Assessment Undertaken By: **(Investigator)**	**Assessment Verified By:** **(Technician or other competent person)**
Name: Bobbie Butters	Name: Chris Edmundson
Signed:	Signed:
Date: 12/02/2018	Date: 20/06/18
Note: Risk Assessment is valid for* ***one year* *from the date given above. Risk Assessments for activities lasting longer than one year should be reviewed annually.*	
Countersigned by Head of School or Chair of H&S Committee: ADRIAN IBBERTSON	
Date: 25th June 2018	

Risk Assessment For:
Activity: Lifters performing overhead movements (Snatch)

Location of Activity: Biomechanics lab: Darwin Building

List significant / potential hazards	List groups of people who are at risk	Level of Risk (high, medium, low)	List the action / safety precautions needed.
Weights plates sliding off the bar when lifted above head. Especially if the lifter is lifting slightly unevenly.	Participant	Medium	Correct use of collars at all times
Set up of the lab must be spacious, in case the lifter feels faint or has to walk with the bar above head.	Participants and researcher	Medium	All equipment that's not required for the testing must be cleared away, personal belongings unused chairs and tables. The necessary equipment should be checked prior to testing to avoid malfunctions and electrical faults.
Risk of potential injury	Participants	Medium	A full PARQ+1 form will be filled out by each participants as part of the screening process. An efficient warm up must take place before any lifting occurs. Including mobilisation, muscle activation drills and pulse raising. Focusing

			on preparing for the lift required for this experiment. Participants should be wearing appropriate attire including suitable footwear. All participants will be completing their lifting under the supervision of the researcher; no lone lifting.
Termination of lifting test	Participant	Low	The participant may end the test at any time by verbal or visual feedback. Researcher will terminate the test if there are evident signs of physical distress
Tripping on wires in the lab	Participants and researcher	Medium	Ensure wires are as out of the way as possible and make everyone involved in the activity aware of where they are. Locate first aid kit and check to make sure it is fully stocked.
First Aid and Emergency procedures	Participants and researchers	Low	A qualified first aid staff will be available at all times. In the lab there is an emergency telephone and a defibrillator which will be identified before testing commences.

Slipping on a wet surface	Participants and researchers	Medium	No food or drink it to be consumed in the lab, if participants need to eat or drink they need to step outside. Locate first aid kit and check to make sure it is fully stocked.
Potential Fire (Keep Fire doors clear)	Participants and researchers	High	Allocate all fire exits, and go through the fire safety procedure before activity commences. Make the participants aware of where they should head to in case of a fire. Ensure there is nothing blocking the fire exits.
Faulty Equipment	Participants	Medium	Ensure that equipment is safe to use, by checking over and testing the apparatus with the technician or competent personnel.
Heavy equipment left out	Participants and researchers	Medium	All equipment will be put away safely in there allocated place and any heavy equipment will be safely and correctly put back with multiple people if required.
Broken Glass on the floor	Participants and researchers	Low	Clear away the broken glass thoroughly before participants enter.

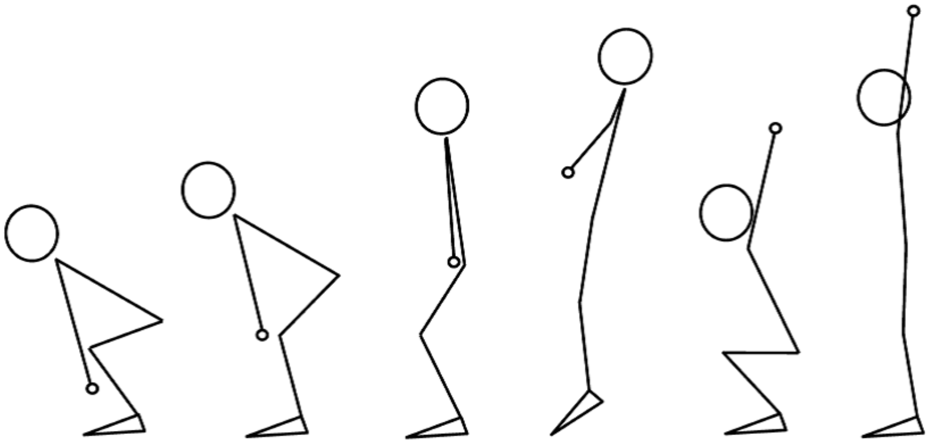
Appendix F: Advertisement

Wanted! Male Olympic Weightlifters

Does the start position, based on anthropometrics, influence the outcome of the Snatch in experienced male weightlifters?

Complete 3 trials of the snatch Olympic lift with 85% of your most recent one repetition maximum; (retrieved in the last 3 months)

It is understood throughout research that individual anthropometrics play a role in Olympic lifting and recently it has become evident that limb length ratios may influence the type of barbell trajectory created by the lifter. This study aims to extend current knowledge and aid fellow scientists, coaches and athletes in understanding the snatch lift, in more individualistic terms.



Requirements

- ✓ **Male**
- ✓ **Age between 18-40 yrs.**
- ✓ **Weight class 62kg-94kg**
- ✓ **2 years consistent lifting experience/Compete at a national level**

This research has been reviewed and approved by the University STEMH Ethics Committee (STEMH 905).

For further information contact **Bobbie Butters:** bbutters@uclan.ac.uk

Appendix G: Recruitment Presentation

uclan

Does the start position, based on anthropometrics, influence the outcome of the snatch in experienced male weightlifters?

What is the purpose of this study?

uclan

- I want to extend the current knowledge and understanding of the Olympic lifts (snatch) to aid coaches and athletes.
- Begin to further modernise current coaching strategies and approach to improving performance in the snatch
- Begin to further Improve the approach to individualisation within British weightlifting

What research has been done so far

uclan

- The start position is a fundamental part of the lift- Sets the lift up for success
- It has been suggested (through the use of a case study) that each lifter has an optimal start position. Based on internal angle of the hip joint
- Limb length rations of an individual plays a role in barbell trajectory
- Higher ranked athletes, have similar limb length ratios and similar bar paths
- Success of a lift declines when the direction of the bar path from the start position is different

My study What I am analysing

uclan

- Individual limb length rations, particular interest in the **femur length: torso length**
- What barbell trajectory is achieved- Direction and magnitude of force from the start position.
- Individual Hip angle adopted at the start position
- Using QTM, Kistler Force platform and V3D

Inclusion Criteria

- Male
- Age between 18-40 yrs
- Weight class 62kg-94kg
- 2 years consistent lifting experience AND/OR competing at a national level

Requirements

Complete 3 trials of the snatch Olympic lifts with 85% of your most recent 1RM (retrieved in the last 3 months)

Testing day

Thursday 17th Jan:

Time Slots

- 10:30am-1pm
- 3:30-5pm

If anyone else interested and is able to participate email me at: **bbutters@uclan.ac.uk**

ANY QUESTIONS?

Appendix H: Regression Analysis

H.1 Absolute Hip Height and all Anthropometric Variables

Model Summary

					Change Statistics				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
1	.584[a]	.342	.305	.06167	.342	9.335	1	18	.007

a. Predictors: (Constant), FEMUR_LENGTH

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.036	1	.036	9.335	.007[b]
	Residual	.068	18	.004		
	Total	.104	19			

ANOVA[a]

a. Dependent Variable: HIP_HEIGHT
b. Predictors: (constant), FEMUR_LENGTH

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1	(constant)	.039	.169		.232	.819		
	FEMUR_LENGTH	1.201	.393	.584	3.055	.007	1.000	1.000

a. Dependent Variable: HIP_HEIGHT

H.1.1 Absolute Hip Height and Limb Length Ratios

Model Summary

					Change Statistics				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
1	.451[a]	.203	.159	.06783	.203	4.596	1	18	.046

a. Predictors: (Constant), SHANK_FEMUR_RATIO

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.021	1	.021	4.596	.046[b]
	Residual	.083	18	.005		
	Total	.104	19			

ANOVA[a]

a. Dependent Variable: HIP_HEIGHT
b. Predictors: (constant), FEMUR_LENGTH

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1	(constant)	.959	.189		5.059	.000		
	SHANK_FEMUR_RATIO	-.429	.200	-.451	-2.144	.046	1.000	1.000

a. Dependent Variable: HIP_HEIGHT

H.1.2 Absolute Hip Height and Anthropometric Variables relative to height

Model Summary

					Change Statistics				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
1	.477[a]	.228	.185	.06679	.228	5.304	1	18	.033

a. Predictors: (Constant), FEMUR_HEIGHT

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.024	1	.024	5.304	.033[b]
	Residual	.080	18	.004		
	Total	.104	19			

ANOVA[a]

a. Dependent Variable: HIP_HEIGHT

b. Predictors: (constant), FEMUR_HEIGHT

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1	(constant)	.021	.232		.0.93	.927		
	FEMUR_HEIGHT	2.153	.935	.477	2.303	.033	1.000	1.000

a. Dependent Variable: HIP_HEIGHT

H.2 Relative Hip Height and all Anthropometric Variables

Model Summary

					Change Statistics				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
1	.473[a]	.224	.181	.03564	.224	5.185	1	18	.035

a. Predictors: (Constant), SHANK_FEMUR_RATIO

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.007	1	.007	5.185	.035[b]
	Residual	.023	18	.001		
	Total	.129	19			

ANOVA[a]

a. Dependent Variable: RELATIVE_HIP_HEIGHT
b. Predictors: (constant), SHANK_FEMUR_RATIO

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1	(constant)	.545	.100		5.478	.000		
	SHANK_FEMUR_RATIO	-.239	.105	-.473	-2.277	.035	1.000	1.000

a. Dependent Variable: RELATIVE_HIP_HEIGHT

H.2.1 Relative Hip Height and Absolute Anthropometric Variables

Model Summary

					Change Statistics				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
1	.449[a]	.201	.157	.03615	.201	4.533	1	18	.047

a. Predictors: (Constant), FEMUR_LENGTH

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.006	1	.006	4.533	.047[b]
	Residual	.024	18	.001		
	Total	.029	19			

ANOVA[a]

a. Dependent Variable: RELATIVE_HIP_HEIGHT
b. Predictors: (constant), FEMUR_LENGTH

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1	(constant)	.109	.099		1.103	.285		
	FEMUR_LENGTH	.490	.230	.449	2.129	.047	1.000	1.000

a. Dependent Variable: RELATIVE_HIP_HEIGHT

H.3 Maximum Horizontal Barbell Displacement and Absolute Hip Height

Model Summary

					Change Statistics				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
1	.610[a]	.373	.338	.02305	.373	10.694	1	18	.004

a. Predictors: (Constant), HIP_HEIGHT

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.006	1	.006	10.694	.004[b]
	Residual	.010	18	.001		
	Total	.015	19			

ANOVA[a]

a. Dependent Variable: BAR_DIP_FP
b. Predictors: (constant), HIP_HEIGHT

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1	(constant)	.141	.040		3.532	002		
	HIP_HEIGHT	-.234	.271	-.610	-3.270	.004	1.000	1.000

a. Dependent Variable: BAR_DIS_FP

H.4 Ground Reaction Force Vector Angle at the Start Position

Model Summary

					Change Statistics				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
1	.667[a]	.445	.414	1.38710	.445	14.422	1	18	.001
2	.832[b]	.692	.656	1.06260	.247	13.672	1	17	.002
3	.877[c]	.769	.726	.94875	.007	5.325	1	16	.035

a. Predictors: (Constant), RELATIVE_FEMUR_LENGTH
b. Predictors: (Constant), RELATIVE_FEMUR_LENGTH, RELATIVE_TRUNK_LENGTH
c. Predictors: (Constant), RELATIVE_FEMUR_LENGTH, RELATIVE_TRUNK_LENGTH, SHANK_FEMUR_RATIO

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	27.748	1	27.748	14.422	.001[b]
	Residual	34.633	18	1.924		
	Total	62.381	19			
2	Regression	43.186	2	21.593	19.124	.000[c]
	Residual	19.195	17	1.129		
	Total	62.381	19			
3	Regression	47.979	3	15.993	17.767	.000[d]
	Residual	14.402	16	.900		
	Total	62.381	19			

ANOVA[a]

a. Dependent Variable: GROUND_REACTION_FORCE_ANGLE
b. Predictors: (constant), RELATIVE_FEMUR_LENGTH
c. Predictors: (constant), RELATIVE_FEMUR_LENGTH, RELATIVE_TRUNK_LENGTH
d. Predictors: (Constant), RELATIVE_FEMUR_LENGTH, RELATIVE_TRUNK_LENGTH, SHANK_FEMUR_RATIO

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1	(constant)	18.975	4.809		3.946	.001		
	RELATIVE_FEMUR_LENGTH	-73.706	19.409	-.667	-3.798	001	1.000	1.000
2	(constant)	45.731	8.120		-5.866	.000		
	RELATIVE_FEMUR_LENGTH	-91.846	15.657	-.831	-3.698	.000	.902	1.109
	RELATIVE_TRUNK_LENGTH	-88.604	23.962	-.524	-3.698	.002	.902	1.109
3	(constant)	68.858	12.370		5.567	.000		
	RELATIVE_FEMUR_LENGTH	-99.537	14.371	-.901	-6.926	.000	.853	1.172
	RELATIVE_TRUNK_LENGTH	-115.449	24.353	-.683	-4.741	.000	.696	1.437
	SHANK_FEMUR_RATIO	-9.240	4.004	-.316	-2.308	.035	.769	1.301

a. Dependent Variable: GROUND_REACTION_FORCE_ANGLE

Appendix I: Correlations

I.1. Absolute Hip Height and Maximum Horizontal Barbell Displacement

Correlations

		BAR_DIS_FP	HIP_HEIGHT
BAR_DIP_FP	Pearson Correlation	1	-.610**
	Sig. (2-tailed)		.004
	N	20	20
HIP_HEIGHT	Pearson Correlation	-.610**	1
	Sig. (2-tailed)	.004	
	N	20	20

** Correlation is significant at the 0.01 level (2-tailed)

I.2. Absolute Femur Length and Absolute Hip Height

Correlations

		FEMUR LENGTH	HIP_HEIGHT
FEMUR_LENGTH	Pearson Correlation	1	.584**
	Sig. (2-tailed)		.007
	N	20	20
HIP_HEIGHT	Pearson Correlation	.584**	1
	Sig. (2-tailed)	.007	
	N	20	20

** Correlation is significant at the 0.01 level (2-tailed)

I.3. Absolute Femur Length and Maximum Horizontal Barbell Displacement

Correlations

		FEMUR LENGTH	BAR_DIS_FP
FEMUR_LENGTH	Pearson Correlation	1	.-.434
	Sig. (2-tailed)		.056
	N	20	20
BAR_DIS_SP	Pearson Correlation	.-.434	1
	Sig. (2-tailed)	.056	
	N	20	20

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