BIOMECHANICAL DIFFERENCES IN LIFTERS WITH PRE-EXISTING INJURIES DURING THE SNATCH EXERCISE

A Thesis

Presented to the Faculty of

The Department of Kinesiology & The Honors College

East Carolina University

In Fulfillment of the Requirements for

The Honors College Signature Honors Project

By

Evan DeVitto

May 2022

Table of Contents

Chapter I. Introduction

High intensity weightlifting (HIW) has grown in popularity across the world. One of the most notable HIW programs is CrossFit. CrossFit is being utilized by a wide variety of participants. Participants can range from professionals that compete at a high level, to the average adult who works a desk job. With HIW programs on the rise, many researchers have taken interest in understanding HIW lifting mechanics and injury rates. HIW utilize 2 major Olympic weightlifting movements, the snatch and the clean and jerk. Although interest has increased, the complexity of the movements can deter some people from participating in these workouts.

Olympic weightlifting is composed of two main movements, the snatch and the clean and jerk. The snatch is a complex movement that is prescribed in HIW settings. There has been extensive research on the snatch, but most of this research has been done on top-tier weightlifters (Ho et al., 2014). While this research is very important, it does not consider the other 99% of the participants that partake in HIW. The top 1% of lifters can self-diagnose their technical movements where recreational participants do not have this knowledge.

In a typical workout, Olympic lifts are prescribed at a specific weight and completed for time (Glassman et al., 2019). There are some people that believe that these exercises are risky for the participants involved. These exercises are designed to be performed at a high intensity that promotes the onset of fatigue faster than traditional workouts. This stress that is put on the body can be handled by professionals that train competitively but for the average person that is participating recreationally this intensity level is something that not everyone can handle. Many recreational lifters do not focus on time, instead they are focused on form and results. Adding the sense of urgency to go as a fast as possible might result in changes in mechanical technique throughout the workout. These potential technique alterations have been suggested as possibly placing HIW participants at a higher injury risk (Hak, 2013). However, little research exists on biomechanical technique alterations that may lead to injury during Olympic weightlifting movements. There is also little research on how technique alterations can lead to an increased injury risk. If researchers can quantify mechanical alterations after multiple lifting attempts, then they may be able to aid athletes during high intensity weightlifting workouts and help minimize technique alterations. Minimizing technique alterations may improve performance and reduce the risk of injury in HIW activities.

Along with improved performance from rectifying the technique alterations, proper technique can also lead to a decreased re-injury rate in certain segments. The goal of HIW workouts is to put the body into a high intensity state. With this intensity state fatigue is expected throughout the workout rather than succeeding the workout. Fatigue is one of the main factors in the decline of lifting mechanics (Trenton, 2017), as HIW workouts are based off consecutive repetitions of these highly technical movements.

In a study by Hooper et al. (2014) subjects were required to do 55 repeated repetitions of the barbell back squat. They discovered that participants increased their level of trunk flexion as the number of completed repetitions increased. This increased flexion could lead to greater shear stress on the lower back, thus putting subjects at an increased risk for injury. If the participant had previously injured their back, then their risk for injury will be high compared to a healthy athlete. A muscle unit is significantly more susceptible to injury following a strain injury than previously healthy muscle unit (Taylor, 1993).

Although there is a considerable amount of research on how muscle fatigue effects standard movements and exercises, there is very little research has been conducted on its effect on Olympic weightlifting movements. Of this research, very little falls in high intensity workout settings, and specifically regarding the snatch exercise. Of the few studies that have focused on lifting fatigue, none have investigated practical commonly prescribed HIW activities nor the re-injury rate of athletes with a medical history.

Purpose

The purpose of this study is to quantify 3D biomechanical alterations at previous injury segments during a HIW bought of repeated snatch repetitions in recreational HIW athletes.

Hypothesis

We hypothesize that participants will exhibit observable biomechanical technique alterations such as increased trunk flexion, increased knee extension, and decreased maximum bar height as they complete consecutive repetitions of the snatch exercise. By monitoring the areas of alteration, these segments should align with the injury history of the participant.

Delimitations

1) All participants will be healthy without any current musculoskeletal or neurological injuries that would impair their ability to perform a snatch weightlifting exercise.

2) All participants will be current weightlifters or HIW athletes at the recreation or competitive level, ages 18 – 45 years.

3) All participants will have at least 3 months' experience doing the snatch movement.

Limitations

1) The analysis is limited to the accuracy of the motion capture system

2) The rest time between repetitions is left up to the athlete's discretion and will not be controlled to simulate normal performance.

3) The initial injuries will be self-reported and not reported by a medical provider.

Chapter II Literature Review

High intensity weight training (HIW) has been growing in popularity over the past several years. There are more than 13,000 high intensity weight training facilities across the world, and that number is continuing to grow. HIW commonly utilizes 2 Olympic weightlifting movements, the snatch and the clean and jerk. With HIW programs on the rise, many researchers have taken interest in understanding HIW lifting mechanics and injury rates. Along with initial injury rates, re-injury rates are also a point of contention among available research. To bridge this gap in research, this study is aimed to look at biomechanical differences in healthy body segments and previously injured segments.

Snatch Biomechanics

The snatch is performed when the bar is lifted from the floor to the overhead position in one swift continuous movement and is not complete until the lifter is standing erect in a controlled manner. This movement can be broken up into 3 segments as outlined in the CrossFit Training guide (Glassman, G. (2019)). This first segment is the set-up phase. This phase is where the lifter is in position to begin the lift. Lifters will assume a wide stance with their shoulders over the barbell. The second stage is the execution of the lift. As the bar is lifted, the hips and shoulders raise at the same rate, and then the hips extend rapidly. The barbell is thrown upwards as the lifter catches the bar in a squat position. The final stage is the finishing stage. Once the lifter has caught the bar, they will full extend their arms, hips, and knees holding the barbell above their head. The lift is not considered complete until this lock out or full extension is achieved.

Skill Performance

There are many attributes that go into a successful snatch attempt. These attributes are noted by Stone et al. (2006) as strength, rate of force development, and power. As these are all multifaceted, which is why the snatch is a very complex movement. A common variable studied to gauge snatch technique is the horizontal displacement of the barbell throughout the lift (Hoover et al. 2006). Horizontal displacement can be an indicator of how stable or unstable the lifter is. An overwhelming amount of literature reports that a large horizontal displacement is detrimental to the lift. If the bar does not stay within the frame of the lifter, then the lift can fail due to displacement of the center of gravity. In study competed by Kipp, K., & Meinerz, C. (2017) the unsuccessful attempts showed that the bar movement moved forward around 10 cm on average. The results indicated that unsuccessful power clean attempts were characterized primarily by differences during the second pull phase. This phase is present when the barbell is transitioned from the knees to the catch squat position.

Another variable that has a lot of research surrounding the topic bar trajectory. Although a study by Chiu et al. (2010) stated there is a common vertical direction of the barbell, there is no definitive bar trajectory for each lifter due to differentiations of horizontal movement patterns. The lifter wants to keep the barbell as close to the body frame as possible to minimize the distance the bar travels. Minimize the time it takes to get the bar into the turnover phase is important in the bar’s trajectory. Garhammer (1985) found this amount of time to be between 0.30 and 0.38 seconds.

Injury

While popularity of HIW workouts have increased, there is still a need for research about HIW workouts. The complexity of movements that is required to successfully complete some of the lifts can deter people from attempting this type of exercise. There are some that consider these exercises to be dangerous. This danger is also heightened as the level of fatigue increases throughout the workout. In a study completed Trenton Salo in 2017 it showed that there were significant reductions in the balance tests that they used as a baseline. The pre- and post- testing scores signified that there are significant influences in the effects of fatigue on one’s biomechanics throughout the lift. However, there is little evidence that supports the safety claims of HIW workouts specifically. In a study completed by Hak in 2013, it was found that the injury rate for HIW athletes were 3.1injuries per 1000 hours trained. This number is similar to that reported for sports such as Olympic weightlifting and power lifting. Compared to the injury rates in team sports, it was found that the team sports injury rate was much higher at 14 per 1000 hours Matesz (2018). Fatigue plays a role in all exercise related activities, so differentiating the injuries that are isolated through HIW has yet to be researched.

Along with injuries that happen during workouts, pre-existing injuries can also affect biomechanics while lifting. A concern during weightlifting is asymmetry during lifting. A pre-existing injury can shift how the weight is carried throughout an exercise. In the snatch exercise the vertical and horizontal imbalance begins when the barbell is at the knee and hip contact points (Khasin, 2022). The asymmetry does not correct through the lift as the peak acceleration and forces were different from the left to the right side. In a study completed by Lake in 2010 they compared symmetry of lifting on participants dominant side (DS) versus the non-dominant side (NDS). They found that the participants said that they felt no difference from the DS to the NDS, but the force output for each side was significantly different from the DS to the NDS. Asymmetries can lead to poor performance, and injury. Lower body asymmetries can lead to lower body pain, as well as back pain (Owens, 2011). In the snatch, the back is under immense pressure, by adding an imbalance a significant injury can occur. Asymmetries are dependent on factors such as neuromuscular, perceptual, kinesthetic requirements. The experience level of a specific HIW or exercise can also affect the symmetry of their movements.

Video Analysis vs. Motion Capture

Until recently, weightlifting research has been populated largely with studies involving 2-dimensional kinematics. (Ho, 2014; Olaya-Mira, 2020; Soriano, 2019). Researchers specify anatomical landmarks on the participants, and on one side of the barbell adjacent to the participant. This method only observed sagittal plane movement. Information and measurements regarding movement in the other planes (transverse and frontal) is still unexplored as technology in the past has been limited. Another big concern of conducting 2-dimensional kinematics on weightlifting movements in the sagittal plane is the period of time where the camera view is blocked by the weight on the bar. This obstruction prevents seeing how the athlete’s ankles are at the start of the lift, athletes knee angle for most of the pulling phases, and the point of contact when the bar meets the hips (Gourgoulis et al. 2002). However, by using a 3-dimensional camera, when the weight blocks the view of one camera, there will be others that can still transmit a signal to the receptors.

The differentiation of lifts in competition settings is also a known problem associated with 2-dimensional weightlifting studies. In competition, athletes are attempting near maximum weight with added performance pressure causing lifting patterns to vary. The biomechanics of the lifts can change based on weight relative to their 1RM. Even the slightest variation in movement changes the lifter's angle to the camera, thus making all analysis inaccurate (Chiu et al. 2010). Conclusions drawn from data collection in 2D can be flawed as axial rotation upon the transverse plane is not detected (Ho, 2014). In HIW workouts, there is much more possibility for variability compared to 1 repetition maximum lifts due to the lengthy repetition schemes and buildup of fatigue. By utilizing a 3-dimensional camera system, the variability is decreased as the exercises progresses.

Summary

High intensity workouts have grown in popularity throughout the fitness industry as a means of exercise for the everyday population. While most enjoy the benefits that these workouts provide, there is also an increased concern regarding the injury protentional. Movements, such as the snatch, are very complex and can lead to injury if not executed properly. In addition to the difficulty of these movements, HIW athletes must do them repeatedly often till failure. Muscle fatigue has been shown to change movement biomechanics and may put athletes at an increased rate of injury during HIW routines. Coupled with preexisting injuries the biomechanical breakdown in form can further lead to injury if not executed correctly.

Preexisting weightlifting research has focused on multiple interest areas such as joint kinematics and barbell trends. It has also used numerous different methods such as quantitative kinematic analysis and qualitative coaching instruction Yet with all the approaches from the past, there are numerous gaps in the preexisting literature on high intensity weighting and the snatch exercise. This study aims to examine the differences in biomechanical breakdowns in healthy participants compared to those with pre-existing injuries in specific body segments.

Chapter III. Methods

Participants

There were 17 recreational weightlifters that served as participants in this study. These participants ranged in age from the ages of 18 years to 45 years old and consisted of a combination of both males and females. Each participant had at least 3 months' experience doing the snatch movement. Participants were excluded from the study if they had any current musculoskeletal or neurological injuries that would impair their ability to perform a snatch weightlifting exercise. Each participant completed an informed consent document as well as a demographic information sheet. The protocol consisted of each participant completing a workout at a CrossFit Tier 1training facility during a one-time visit that lasted approximately 45 minutes to 1 hour.

Procedure

Before arriving at for data collection, participants were told to wear a tight-fitting shirt or sports bra, spandex shorts, and their own weightlifting shoes. The tight-fitting clothing ensured that the markers would give accurate readings for each segment. Once the participant arrived, they were asked to fill out a short questionnaire regarding age, gender, musculoskeletal or neurological injury history, perceived ability to perform a snatch weightlifting exercise, experience with the snatch movement, estimated one rep snatch maximum in pounds, and experience in HIW. The participant's height and weight were also recorded.

Utilizing a ten-camera (infrared) 3D motion capture system (Opus 300+ Cameras, Qualisys, Goteborg, Sweden), kinematic data was taken at a sampling frequency of 200 Hz in the frontal, sagittal, and transverse planes. 36 reflective markers were placed bilaterally on the participant's calcanei, first and fifth metatarsal heads, medial and lateral malleoli, medial and lateral femoral epicondyles, anterior and posterior superior iliac spines, greater trochanters, iliac crests, greater tubercles, radial groove, acromion's, lateral epicondyles of the humerus, ulnar shaft, radial shaft, and both ends of the barbell sleeves. 2 singular markers were placed on C7 vertebra and the jugular notch of the sternum. Marker plates with four markers each were utilized on the lateral side of the participant's thighs, shanks, and the tops of the metatarsals. All markers and marker plates were placed prior to the participants warm up to ensure adherence to the skin during the study protocol.

One static trial was conducted. During the trial, the participant stood still in the middle of the calibrated area with arms raised to shoulder level in a T-pose to establish a relative position between tracking clusters and anatomical landmarks. Before starting the workout trial, the static markers were removed (iliac crests, greater trochanters, medial and lateral femoral condyles, medial and lateral malleoli, and first and fifth metatarsal heads). Participants were allowed to complete a warmup of their choosing to build up to the weight selected for data collection. If any markers fell off during the warmup the markers were reattached, and the static trial was repeated.

The weight used for collection is subject specific and was based off 60% of the participant's estimated one rep max snatch. Each participant completed the HIW benchmark workout "Isabel" which consists of 30 repetitions of the snatch for time. The weight lifted was held consistent for all 30 repetitions. Participants were allowed to take as much rest between repetitions as they desire but had a goal of completing the 30 repetitions as fast as possible. An official repetition count was provided every 5^{th} lift to ensure the participant stayed on track throughout the workout. There was also an official clock provided to all participants so they could track their own time.

Data analysis

Marker data were integrated and processed using Qualisys Software (Qualisys, Goteborg, Sweden). A biomechanical model was created in Visual 3D Software using the markers placed on the participate during data collection. (C-Motion, Germantown, Maryland). The participant's height, weight, and static calibration trial were used to scale the model accordingly. Kinematic data were derived from the biomechanical model movements based on the 3D trajectory of the reflective markers. All 30 lifts were analyzed for each condition in each participant. The kinematic and kinetic variables of interest are 3D body segment positions and joint angles, bar height, and bar location relative to the lifter. The first repetition for each participant were used as a baseline, and differences from baseline for each variable were calculated. By comparing healthy participants to those with pre-existing injuries, the difference between injured segments can be analyzed. From looking at the health questionnaires that the participants submitted we were able to separate them into two subcategories, healthy and previously injured. Based on the injuries that each participant had, we matched them to their best match from the healthy pool. To pair the participants together we compared the demographics of each participant's pool. We paired participants that were similar in height, weight, as well as experience.

Asymmetry between segments was also analyzed as the workout progressed. The goal is to determine if there is a significant breakdown between healthy and injured body segments. Mean and standard deviations were calculated for each participant.

Chapter IV. Results

The data that was gathered from the study showed that there were biomechanical differences in specific body segments when comparing healthy segments to those with a pre-existing injury. Along with the breakdown in mechanics in previously injured body segments, there is also a general breakdown in mechanics as the exercise progresses.

Within our participant pool we had two participants that had sustained wrist injuries. One subject hurt their wrist two years ago (Participant 2) while the other occurred five years ago (Participant 3). The wrist is an important segment within the snatch movement as the main weight is being pulled through the wrists. If the grip strength is altered by an injury to the wrist, then the mechanics of the overall lift would be changed. To measure the difference in the segments maximum bar height as well as horizontal bar displacement was analyzed. When comparing the two injured participants to the baseline participant's (Participant 1) values we saw that there were several areas of differentiation. The first came during the horizontal displacement of the barbell. The baseline values of participant 1 saw insignificant changes of less than .02m from the left to the right side. This is a relatively normal level of variation among a lift of this speed. Participant 2 saw a difference of .087, while participant 3 saw a difference of .066m from each side. This shows that there is a difference in the horizontal displacement in the barbell and a wrist injury could have caused this. To know if the injury is solely responsible for the variation further testing would be needed. There should also be consideration in the difference in time for each of the injuries. Since Participant's 2 injury was two years ago, the difference in the displacement from participant 3 whose injury was 5 years ago may be contributed to this three-year gap. Further consideration should also be given to the time difference between the injuries.

Additional tests would need to be conducted to determine if the time of injury played any role in the mechanical alterations.

One area that we did not see significant differentiation in was maximum bar height. The data values that were computed, there was not a statistical difference when comparing the left and right sides of the barbell. Knowing that there was a difference in the horizontal displacement and not in the bar height shows that the injury mechanisms could manifest itself differently for each participant. Further studies would be needed to determine if these different values were caused by structural damages from the injuries or if these differences are the effect of biomechanical differences that resulted from the injury. One limitation of the study was that we did not collect information about how they returned to exercise from their exercise or the severity of the exercise. This information would be needed to make a conclusion on why the mechanics present differently for the various body segments.

Another segment that we looked at was the knee. Participant 13 (P13) had a previous knee injury, and they were compared to their comparison match of Participant 5 (P5). The knee is a crucial factor of the snatch movement. Being able to have adequate knee flexion and being able to channel the load through the joint is crucial to the lift. When comparing the starting knee flexion both participants had vastly different degrees of flexion. The healthy participant had an average of 12.5 degrees across both knees, whereas P13 had an average of 2 degrees. Furthermore, P13 had a significant difference across the midline. The left knee, which was previously injured, had 8.5 degrees of flexion and the right knee had an average flexion of 1.7 degrees. The asymmetry between each side of the body at the start of the movement shows the effect that an injury can have on the mechanics of the lift. As each repetition progressed, the flexion between both knees became more symmetrical. During knee pulling phases the knee flexion was almost identical on each side of the body. Seeing that the flexion changes throughout the lift, but the start phase is different, could show of the adaptations that the participant made to accommodate for their injury.

When looking at the right knee compared to the left knee the various degrees of flexion between each side also changed as the lift progressed. The repetition time stay consistent throughout the exercise. Through the first 15 reps and the last 15 reps the average time for each repetition only differed by .04s. While the repetition time didn't change, the knee flexion did. Across the first set of reps compared to the last set, the degree of flexion in the left knew differed by 2.1 degrees.

These results signify that injuries do cause a breakdown in mechanics. While there is not a distinct way that injuries will manifest in each participant, it is important to know the mechanics behind each injury. Knowing that those coming back from injuries are more susceptible to sustaining additional injuries, it's important to understand as we help them in their rehab as well as their training.

Chapter V. Discussion

Pre-existing injuries do affect the biomechanical technique that participants use during the snatch exercise. These changes in technique alter the symmetry of the lift. When looking at the results outlined above it is clear to see that the participants that had a pre-existing injury had asymmetries in the maximum bar height, the horizontal displacement of the barbell, and as well other variables that focus on loading variables.

It will also be important to determine whether the biomechanical alterations are caused by adaptations to the injury. While this is outside the scope of this research, it is a topic that could have substantial impacts on injury mechanics. Participants need to understand the effects that an injury can have on their lifting mechanics. If a participant were to come back early from an injury, they may make alterations to their form to guard the specific muscle groups that were injured. Alicia Montalvo completed a study that was focused on the injury factors for individuals involved with CrossFit. She found that eleven out of 62 injuries that were reported in her study were pre-existing or re-injuries. Of these injuries, 47 were primary injuries that occurred as a direct result of CrossFit participation. Additionally, twenty-four percent of the athletes indicated that their injury did not affect their training while 50% indicated that their reported injury caused them to change their training regimen. Almost 20% of the athletes stated that the injury caused them to stop participating in CrossFit and another 20% of the athletes reported that the injury only caused them to adjust specific exercises within their program (Montalvo, 2016). If only 20% of the participants are stopping due to an injury and the remaining 80% are pushing through the injury then they could be making adaptations that could harm their technique. Making these adaptations could cause long term damages to their exercise routine. While they may believe that these changes are only for the short term, they may be creating habits that could inhibit correct form in the future. To see the effect of the alterations, further research would be needed. Skill performance sessions as well as a quantitative breakdown of their form would be needed to determine if these alterations could be reversed. Further studies will be needed to see of these differences can be corrected with coaching and skill performance-based training. From what the data shows we can see that there is a statical difference in the measurements, but the question we must ask is if these differences are enough to elicit an injury response.

These results will be significant to both healthcare professional and HIT participants. Releasing a patient too early could lead to a severe injury with a longer recovery time. Muscle guarding and other psychological adaptations could be adopted by the lifter to decrease the metal fear of returning to exercise. In a study completed by Fulton in 2014 they found that there was a significant increase in the injury risk after sustaining a previous injury. This particular study looked at several injuries including hamstring strains, ankle sprains, and ACL injuries and found that in all cases the re-injury risk was higher upon the return to play. Reinjury was suggested to be associated with deficits in neuromuscular factors that were present following the injuries (Fulton, 2014). Athletes will want to return to activity as fast as they can to continue to compete. Making sure that they can compete at a high level after sustaining an injury is the primary job of coaches as well as practitioners. Rehab or prevention programs designed by practitioners that address these adaptations in the lift mechanics can target the auxiliary muscles to strengthen the muscle unit. Being able to pull motor units from surrounding muscles can help to decrease the adaptations made by adjusting their technique. Hopefully participants in HIW can better understand their injury risk and allow them to focus on their performance mechanics.

References

Akkus, H. (2012). Kinematic analysis of the snatch lift with elite female weightlifters during the 2010 world weightlifting championship. *Journal of Strength and Conditioning Research, 26*(4), 897-905. doi:10.1519/JSC.0b013e31822e5945

Campos, J., Poletaev, P., Cuesta, A., Pablos, C., & Carratalá, V. (2006). Kinematical analysis of the snatch in elite male junior weightlifters of different weight categories. *Journal of Strength and Conditioning Research, 20*(4), 843. doi:10.1519/R-55551.1

Chiu, H., Wang, C., & Cheng, K. (2010). The three-dimensional kinematics of a barbell during the snatch of taiwanese weightlifters. *Journal of Strength and Conditioning Research, 24*(6), 1520-1526. doi:10.1519/JSC.0b013e3181db23f4

Fulton, J., Wright, K., Kelly, M., Zebrosky, B., Zanis, M., Drvol, C., & Butler, R. (2014). Injury risk is altered by previous injury: A systematic review of the literature and presentation of causative neuromuscular factors. International Journal of Sports Physical Therapy, 9(5), 583-595. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/25328821

Garhammer, J., & Newton, H. (2013). Applied video analysis for coaches: Weightlifting examples. *International Journal of Sports Science & Coaching, 8*(3), 581-594.

Glassman, G. (2019). *Level 1 training guide (2nd ed.)*. Halifax, Nova Scotia (Canada): Crossfit Inc.

Gourgoulis, V., et al.Comparative 3-dimensional kinematic analysis of the snatch technique in elite male and female greek weightlifters. *The Journal of Strength and Conditioning Research, 16*(3), 359.

Gourgoulis, V., Aggeloussis, N., Antoniou, P., Christoforidis, C., Mavromatis, G., & Garas, A. (2002). Comparative 3-dimensional kinematic analysis of the snatch technique in elite male and female greek weightlifters. *Journal of Strength and Conditioning Research, 16*(3), 359-366. doi:10.1519/00124278-200208000-00005

Hak, P. T., Hodzovic, E., & Hickey, B. (2013). The nature and prevalence of injury during CrossFit training. *Journal of Strength and Conditioning Research, Publish Ahead of Print* doi:10.1519/JSC.0000000000000318

Ho, L., Lorenzen, C., Wilson, C., Saunders, J., & Williams, M. (2014). Reviewing current knowledge in snatch performance and technique: The need for future directions in applied research. *Journal of Strength and Conditioning Research, 28*(2), 574-586. doi:10.1519/JSC.0b013e31829c0bf8

Hoover, D. L., Carlson, K. M., Christensen, B. K., & Zebas, C. J. (2006). Biomechanical analysis of women weightlifters during the snatch. *The Journal of Strength and Conditioning Research, 20*(2), 627.

John Garhammer. (1985). Biomechanical profiles of olympic weightlifters. *Journal of Applied Biomechanics, 1*(2), 122-130.

Khasin, L., & Drozdov, A. (2022). Power snatch execution asymmetry capturing method. *Theory and Practice of Physical Culture, 2*, 25-27. Retrieved from http://www.tpfk.ru/index.php/TPPC/article/view/124

Kipp, K., & Meinerz, C. (2017). A biomechanical comparison of successful and unsuccessful power clean attempts. *Sports Biomechanics, 16*(2), 272-282. doi:10.1080/14763141.2016.1249939

Lake, J., Lauder, M., & Smith, N. (2010). The effect that side dominance has on barbell power symmetry during the hang power clean. *Journal of Strength and Conditioning Research, 24*(11), 3180-3185. doi:10.1519/JSC.0b013e3181da77ca

Liu, G., Fekete, G., Yang, H., Ma, J., Sun, D., Mei, Q., & Gu, Y. (2018). Comparative 3-dimensional kinematic analysis of snatch technique between top-elite and sub-elite male weightlifters in 69-kg category. *Heliyon, 4*(7), e00658. doi:10.1016/j.heliyon.2018.e00658

Matesz, D. A. (2018). Benefits of bodybuilding. Retrieved from http://www.fullrangestrength.com/benefits-of-bodybuilding.html

Montalvo, A. M., Shaefer, H., & Rodriguez, B. (2016). Injury epidemiology and risk factors for injury in group-based high intensity power training. Medicine and Science in Sports and Exercise, 48, 867. doi:10.1249/01.mss.0000487599.90040.1b

Olaya-Mira, N., Soto-Cardona, I. C., Palacio-Peña, R. T., & Acevedo-Tangarife, N. J.*Kinematic analysis of the snatch technique in high performance weightlifters* Institut d'Educacio Fisica de Catalunya (INEFC). doi:10.5672/apunts.2014-0983.es.(2020/2).140.10

Owens, E. M., Serrano, A. J., Ramsey, M. W., Mizuguchi, S., Johnston, B., & Stone, M. H. (2011). Comparing lower-limb asymmetries in NCAA D-I male and female athletes. *Journal of Strength and Conditioning Research, 25*, S44-S45. doi:10.1097/01.JSC.0000395647.08972.ca

Soriano, M. A., Suchomel, T. J., & Comfort, P. (2019). Weightlifting overhead pressing derivatives: A review of the literature. *Sports Medicine, 49*(6), 867-885. Retrieved from doi:http://dx.doi.org/10.1007/s40279-019-01096-8

Stone, M. H., O'Bryant, H. S., Williams, F. E., Johnson, R. L., & Pierce, K. C. (1998). Analysis of bar paths during the snatch in elite male weightlifters. *Strength & Conditioning Journal, 20*(4), 30-38.

Stone, M. H., Pierce, K. C., Sands, W. A., & Stone, M. E. (2006). *Weightlifting: A brief overview* Ovid Technologies (Wolters Kluwer Health). doi:10.1519/1533-4295(2006)28[50:wabo]2.0.co;2

Storey, A., & Smith, H. (2012). Unique aspects of competitive weightlifting. *Sports Medicine (Auckland), 42*(9), 769-790. doi:10.1007/BF03262294

Taylor, D. C., Dalton, J. D., Seaber, A. V., & Garrett, W. E. (1993). *Experimental muscle strain injury* SAGE Publications. doi:10.1177/036354659302100205

Trenton D. Salo, & Eric Chaconas. (2017). The effect of fatigue on upper quarter y-balance test scores in recreational weightlifters: A randomized controlled trial. *The International Journal of Sports Physical Therapy, 12*(2), 199-205.

Whitehead, Paul N., et al. (2012). Snatch technique of united states national level weightlifters. *The Journal of Strength and Conditioning Research, 28*(3), 587-591.