

POWER CLEAN TECHNIQUE ANALYSIS

between non-professional experienced,
medium experienced and non-experienced athletes

U. PORTO



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Diogo Morais

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TABLE OF CONTENTS

Acknowledgements.....	III
Table of contents	V
Table of contents - Figures	IX
Table of contents – Tables and graphs.....	XI
Abstract.....	1
Abbreviations	3
Introduction.....	5
Reveiw	9
Weightlifting Schools.....	9
Power Clean Technique Breakdown - Phases.....	12
1. The First Pull.....	13
Transition Phase	13
2. The Second Pull	13
3. Turnover	14
4. Catch	14
5. Recovery.....	14
Power Clean Technique Breakdown - Events.....	15
1. Lift.....	15
2. Knee Cross	15
3. Contact	15
4. Elbow Flexion	15
5. Full Extension	16
6. Barbell Maximum Velocity.....	16
7. Catch First	16
8. Catch Second	16
9. Final Position	17
Power Clean - Technical Performance Points	18
Start Position	18
First Pull.....	18
Second Pull.....	19
After Contact, Extension and Catch Position	19
Power Clean - Technical Details.....	19

Problem	23
Objectives	23
Hypothesis	24
Methods	25
Participants	25
Inclusion Criteria	25
Sample Characterisation.....	25
Procedures and Materials	26
Statistical procedures.....	27
Movement Analysis.....	27
Pipelines Description	28
1. Down sample Targets	28
2. Filter Targets.....	28
3. Event Detection	29
4. Metrics - Phase Duration	30
5. Metrics - Event Instances.....	30
6. Metrics - Bar Trajectory.....	30
7. Metrics - Alignment	31
Results.....	33
Phases - Table 2 - General Analysis	33
Phases - Table 2 - Specific Analysis.....	33
First Pull.....	33
Second Pull.....	34
Turnover	34
Catch	34
Recovery.....	35
Events - Table 3 - General Analysis	36
Events - Table 3 - Specific Analysis.....	36
Knee Cross	36
Contact and Elbow Flexion	37
Elbow Flexion and Barbell Maximum Velocity	38
Barbell Maximum Velocity and Full Extension	38
Full Extension and Catch First	38
Catch First and Catch Second	39
Body Alignments - Table 4 - General Analysis.....	39

Body Alignments - Table 4 - Specific Analysis.....	40
Lift.....	40
Knee Cross	41
Contact	41
Barbell Maximum Velocity.....	41
Full Extension	42
Catch First	42
Catch Second	43
Graphs: Barbell trajectories and Velocities	46
Barbell trajectories - Graph	46
Trajectories Graph Analysis - 40% Lift.....	47
Trajectories Graph Analysis - 60% Lift.....	48
Trajectories Graph Analysis - 80% Lift.....	48
Vertical acceleration - Graph	49
Trajectories Graph General Analysis	49
Velocities Graph Analysis - 40% Lift	50
Velocities Graph Analysis - 60% Lift	50
Velocities Graph Analysis - 80% Lift	51
Technique analysis of the experienced group.....	55
Barbell trajectories - Graph	55
Barbell Trajectory - Analysis	55
Vertical Acceleration - Graph	56
Vertical Acceleration - Analysis.....	57
Body Alignments - Analysis	59
Discussion	61
1. First Pull Phase.....	61
1.1. Lift and Knee Cross	62
First Pull - Full Movement	62
2. Second Pull Phase.....	63
2.1. Contact	63
2.2. Elbow Flexion	64
2.3. Barbell Maximum Velocity.....	65
2.4. Full Extension	67
Second Pull Phase - Full Movement.....	68
3. Turnover	69

4. Catch	70
5. Recovery.....	72
Final ME and NOXP Comparison	73
Conclusion	79
Recommendations for future research.....	83
Bibliography	85

TABLE OF CONTENTS - FIGURES

Figure 1 - Power Clean movement.	12
Figure 2 - Barbell layout and markers placement.	27
Figure 3 - Shoulder and Ankle alignments.	31
Figure 4 - Hip and Knee alignments.	32
Figure 5 – Contact - Full Extension - Catch: A – EXP; B – ME; C – NOXP; D – NOXP....	45
Figure 6 - Trajectories - Experience Dependent –40%, 60% and 80%: No-experience (NOXP) in blue, Medium-experienced (ME) in red and Experienced (EXP) in green.	49
Figure 7 - Velocities - Experience Dependent. A – 40%, B – 60% and C – 80%: No-experience (NOXP) in blue, Medium-experienced (ME) in red and Experienced (EXP) in green.....	52
Figure 8 - Non-Experienced - Trajectory and Velocity: No-experience (NOXP), Medium-experienced (ME) and Experienced (EXP). 40% in blue, 60% in red and 80% in green. .	53
Figure 9 - Medium Experienced - Trajectory and Velocity: No-experience (NOXP), Medium-experienced (ME) and Experienced (EXP). 40% in blue, 60% in red and 80% in green.....	54
Figure 10 - Experienced Group - Barbell Trajectory and Velocity - 40% in blue, 60% in red and 80% in green.....	58
Figure 11 - Lift to knee cross	59
Figure 12 - Dynamics of going from Full Extension to Catch First and Catch Second - Experienced Group.....	60

TABLE OF CONTENTS – TABLES AND GRAPHS

Table 1 - Sample Characterisation, according to expertise: Experienced (EXP), Medium-experienced (ME) and No-experience (NOXP) athletes.	26
Table 2 - Phases duration comparison, for the 5 phases, presented in percentages, for each load (40%, 60% and 80%), between expertise levels: Experienced (EXP), Medium-experienced (ME) and No-experience (NOXP) athletes.	35
Table 3 - Events instants occurrence comparison, for 7 events, presented in percentages, for each load (40%, 60% and 80%), between expertise levels: Experienced (EXP), Medium-experienced (ME) and No-experience (NOXP) athletes.	39
Table 4 - Body Alignments comparison in all phases and events, for the alignments between shoulder/ ankle, and knee/ hip, in horizontal and vertical plane. Presented in meters, for each load (40%, 60% and 80%), between expertise levels: Experienced (EXP), Medium-experienced (ME) and No-experience (NOXP) athletes.	44

ABSTRACT

The purpose of this study is to identify differences in Power Clean technique among novice, medium, and experienced athletes, and to provide tools for improved coaching and teaching. It aims to identify problematic technical phases, events and common errors, that novices and medium experienced athletes may encounter while learning. This data may provide additional tools for coaches and athletes to sharpen technique progressions, by previously knowing what they should expect to see in the learning curve.

Forty five healthy and physically active participants were divided into three groups based on their levels of experience with weightlifting: non-experienced, medium experienced, and experienced athletes.

A hybrid motion capture system, comprising markerless and marker-based Qualisys cameras, was used to capture the participants movement. Data was collected simultaneously and synchronously, in the Qualisys Track Manager software (Qualisys AB, Sweden). The marker-based system, composed by 12 Oqus cameras, operating at 100 Hz, registered the barbell movement. The markerless system was used to record the participants body movement, and it was composed by 8 Miquis Video cameras operating at 100 Hz and 720p resolution. Simultaneously, ground reaction forces data was collected in synchrony with the motion capture system, at a frequency of 1000 Hz.

The markerless video data was then processed on Theia v2022.1.0.2309 (Theia Markerless, Canada) and the resulting detected movements were then exported to Visual3D v.2021.11.3 (C-Motion, USA), where further calculations were made.

Findings revealed that some technical mistakes seemed to emerge during the learning process. For example, rushing the barbell off the floor, and an extremely early elbow flexion seems to be more evident in the medium experienced group, when comparing to the non-experienced one. This suggests that some errors seem to be either learnt, mistaught or wrongfully understood, and that different approaches when teaching should be taken into account to minimize the potential of wrong information to be kept.

Key considerations when teaching the Power Clean include the understanding of the correct events order of appearance, as well as their timings and durations, as well as proper body alignments. Data also suggests that achieving a certain level of proficiency

may be necessary for athletes to fully benefit from the Power Clean and recommends further research to better understand the relationship between expertise levels and performance enhancement outcomes.

Keywords: Non-professional weightlifting, Power Clean, Technique, Learning, Body alignments.

ABBREVIATIONS

1RM - 1 Repetition maximum

AP - Anterior-posterior

ABS - Absolute

ASCII - American Standard Code for Information Interchange

BMI - Body Mass Index

C3D - Coordinate 3 Dimensional

CMZ - Compressed Posed Camera Set

EXP - Experienced Group

GRF - Ground Reaction Forces

ME - Medium Experienced Group

ML - Medial-lateral

N - Newtons

NORM - Normalised

NOXP - No-Experience Group

R_Ak - Right Ankle

R_Bar - Right side of the barbell

R_Kn - Right Knee

R_Elb - Right Elbow

R_Sh - Right Shoulder

RFD - Rate of Force Development

CMJ - Counter Movement Jump

SJ - Squat Jump

INTRODUCTION

Weightlifting is a strength and power sport, in which two lifts are contested. The two lifts, in order of execution in a contest, are the Snatch and the Clean and Jerk (Stone, 2006).

The Snatch and the Clean and Jerk are two distinct movements, with several similar performance key points, and a common objective: lifting an Olympic barbell starting with the weight resting on a platform, to a final position, above the head, with lower limbs, hips and arms in full extension. The difference between the two lifts, is in the method: Snatch is a single movement. The Clean and Jerk consists of a two-stroke movement, in which the barbell is raised and placed on the shoulders through a Clean, until the final position, above the head, in complete extension, through the Jerk (Everett, 2014). In a competition, the winner is the one who has the highest sum of the mass lifted in the two movements, within very strict rules (Kipp, 2012).

Some particularities of this modality have shown to be interesting for several sports, due to its great capacities transfer, related to its strength, explosive strength, and ballistic characteristics.

No training method should be considered as “the one and only” to develop such sports capacities, but weightlifting might be considered as a good option in training plans, due to some advantages suggested in the available literature.

Virtually any sport that needs either strength, explosive power or speed, can benefit from weightlifting training, or by some of its technique variations. Also, and despite the fact that weightlifting itself may not mimic some sports specific movements, literature consistently provides enough evidence that Olympic lifts and their derivatives can improve the rate of force production, high-load speed strength, maximum strength, and vertical jump performance while using dynamic postures (Universal Athletic Position) commonly seen in many sports (Sutton, 2021).

In short, weightlifting seems to better develop jumping capacity than powerlifting (Hoffman et al., 2004). It is likely to develop more strength than kettlebell training (Otto et al., 2012). Compared to traditional resistance training, it appears to better develop the Counter Movement Jump (CMJ), which is a high standard test of explosive strength.

The similarity between the jump that occurs after the second pull in weightlifting under load and the pattern of the countermovement jump (CMJ) can be explained by the triple extension technique that occurs in weightlifting. (Berton et al., 2018). It is more likely to enhance, at a greater scale, 10 meters sprint time, Squat Jump (SJ), CMJ and half squat 1 maximum repetition (1RM), while compared to jump training programs. Literature also suggests that, due to a development of a wide spectrum of capacities, sports specific tasks should have a greater amount of transfer (Tricoli et al., 2005).

The Power Clean specifically (one of the weightlifting derivatives), seems to target directly the mid-section of the Force-Velocity curve, where it sits the highest power output (Suchomel et al., 2017). Alongside, a well-developed Rate of Force Development (RFD) is fundamental to several sports, as it is linked to higher jumps and better sprints. For instance, the RFD in a Power Clean is similar to the one found in Squat Jumps. Similarly, to succeed in weightlifting, a high RFD has to be developed and high rates are linked to better results in weightlifting as a sport (Walker, 2016).

Strength and power values can then be greatly explored, improving capacities as the ones above, due to the particular characteristics of different phases of the techniques, which can specifically address those very important sports related items (Hadi et al., 2012; Lee et al., 1995).

In sum, weightlifting as a targeted training method, can help to balance and develop the Force-Velocity (FV) curve, improve the RFD, jumps, sprints and general strength, which in turn can be helpful to improve athleticism for a very wide range of sports. Nevertheless, it is important to refer that even professional weightlifters do not use exclusively weightlifting movements. Training sessions and programming have to be a well-structured compound. Findings suggest that it is important to develop a solid strength base, as a foundation prior to work on the ballistic characteristics of weightlifting and its derivatives (Cormie et al., 2010). This is supported by the evidence that shows weightlifting better enhances sport specific physical capacities, when combined with traditional resistance training. Especially when intensities are targeted above 75% of a 1RM (García-Valverde et al., 2022).

Now that some uses and applicabilities of Olympic weightlifting in other sports have been established, some limitations should be addressed. One of the main difficulties rests on the complexities of this technique, in which the “catch” and “recovery” phases can be an issue. A great amount of time must be spent by a non-weightlifting athlete to learn, master

and use the techniques properly, taking full advantage of their characteristics, which can compromise their time available for sport specific training. Sometimes, to simplify movements, some variants are introduced. These variants may not require a full squat, or may even not require a “catch” (Carlock et al., 2004; Hackett et al., 2016; Storey & Smith, 2012; Sutton, 2021). Two of the possible variants that do not require a full squat and, consequently, a higher technical level “catch” phase, are the Power Snatch and Power Clean, which are two widely used training methods (Sutton, 2021). Interestingly, even though these techniques are not the full movement, they have a very powerful range of advantages, as the ones stated above. This means that several benefits can be taken from them, even with less time spent on technique training than it should take to master the complete techniques.

However, the complexity of these techniques, even if variants are used, requires a considerable amount of time on refinement, if one is to take good advantage of them as a training method to develop specific capacities. This means that both for the athlete and for the coach, it is important to know where to look at when teaching, and where the most common errors are to be found while learning. Having problematic details identified can translate into less teaching, coaching and refining time, which in turn translates into less time spent on learning and more time spent on general and specific training. Also, proper technique transversely translates into better movements. Better movements should then translate into more advantages taken from the characteristics of these techniques. Nevertheless, this limitation might also dictate a virtue, once it seems that the technique complexity helps to develop a wider range of capacities, which in turn transfer to sports specific needs (Teo et al., 2016).

The purpose of this study is to identify problematic technical phases, events, or technical details to novice and medium experienced athletes, and to provide tools for better coach and teaching. It also aims to provide objective data that may help a coach who has little knowledge on the technique to better understand where to look at, and what it is supposed to happen across the learning curve of an unexperienced athlete.

To narrow down the data and maximize detail, in the current study we have focused on the Power Clean technique, as it is known to target the maximum power output area of the force-velocity curve and is primarily focused on lower body and trunk power.

REVEIEW

Weightlifting Schools

Weightlifting, also known as Olympic weightlifting, is a sport that requires high levels of strength, power, and technique. Techniques will have different approaches and philosophies, depending on which school we are looking at. There are several schools, but three of the most known weightlifting schools are the Bulgarian, the Russian and the Chinese. All of them have had great success in international competitions.

- **Bulgarian**

The Bulgarian Weightlifting School, was founded by Ivan Abadjiev (1930-2012). It is known for its high-intensity, high-volume training approach, which emphasizes heavy lifting and frequent competition participation. The school's athletes are known for their very high strength and power (Everett, 2014; Kurz, 2001).

- **Russian**

Another well-known weightlifting school is the Russian Weightlifting School, which is known for its emphasis on technique and form, as well as its use of specialized exercises to target specific muscle groups (Siff, 2009). The school's athletes are known for their precision and technical proficiency.

- **Chinese**

A third well-known weightlifting school is the Chinese Weightlifting School, but is not an easy task to find literature about it, (as it also is very hard to find written specific details about any school in particular). For example, specific details about the Chinese school rely on the anthropometry of their athletes in general. As they generally have shorter limb lengths, they often use the Squat Jerk instead of Power Jerk or Split Jerk. They usually present a Clean and Jerk wider grip, as well as display a pronounced back hyper extension, in order to gain a few centimetres more in the barbell height in contact and in full extension. (Everett, 2014; Torokhtiy, 2022).

In sum, this does not mean that one school is better than the other. There are simply minor adjustments that are made, according to some specificities, but all of them have presented successful lifters. As in any other sport, it is expected to see, even inside each school

philosophy, minor technical adjustments to be applied, for example, to athletes with different body proportions.

Having this in mind, empiric knowledge is the best way to understand specific differences between schools and their approaches. It is through discussion with coaches from different schools and visualising their athletes performing that one can better understand differences between them.

Also, as in any other sport, different schools will have different approaches in training loadings and volumes and these must be the main differences to be found among them.

A dissection and performance points characterisation of the Power Clean was made, aiming for better parameters readings and analysis. This breakdown is based on literature available and on the experience and knowledge acquired by learning closely with a 20 year plus athlete and coach, Olympian and holder of European and World titles, Oleksiy Torokhtiy. This was gathered in a continuous 5 year timeframe, through participation in several seminars and direct contact learning. It also reflects my personal experience as a coach, coaching weightlifting techniques to several hundreds of athletes, for 6 years, on a daily basis.

As stated above, different schools have different approaches, readings and philosophies. Despite this, generally speaking, the techniques are the same. There are details and specificities that will be different, also because different body types need to have specific technical adjustments, but the movement itself is the same, with very similar key points (Torokhtiy, 2022). This means that these minor technical differences of different school techniques are not relevant for this study. These specific adjustments are obviously important if the goal is to lift the maximum amount of weight possible to win weightlifting competitions. This is not the case being discussed here. Plain simple, it will be presented general performance key points, that are important to watch, to guarantee a good or high level of technique proficiency. Not to win in weightlifting, but to take the most out of this training method, to enhance specific capacities to a different sport.

Firstly, the technique will be broken down into phases, and then subdivided in events. Breaking down the technique allows both coach and athlete to better understand what is supposed to occur in every specific movement block, because each one has its own purpose.

After the break down is completed, the technique will be described as, in general, it should be correctly performed.

Power Clean Technique Breakdown - Phases

The technique phases names can be different or divided in different ways, according to the philosophies of different schools. The ones presented below are based both on Aleksey Torokhtiy book “Clean Masterclass” and on other researches:

1. First Pull
2. Transition Phase (not registered in this study)
3. Second Pull
4. Turnover
5. Catch (or receiving position)
6. Recovery

Figure 1 - Power Clean movement.

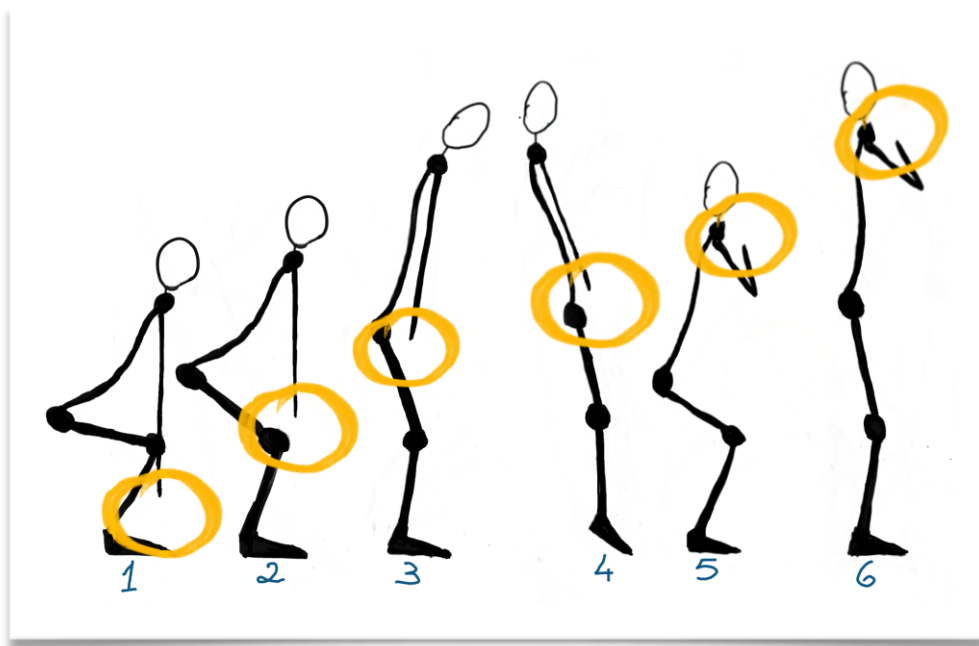


Figure 1 above visually recreates the Power Clean movement.

- Number 1 and 2 represent the First Pull.
- Numbers 2 to 4 correspond to the Second Pull.
- Turnover from 4 to 5, 5 being the Catch
- Recovery from 5 to 6.

1. The First Pull

This phase is comprehended between the moment where the barbell loses contact with the floor and the moment where the knee ceases to extend, in other words, where the knees reach their first maximum extension (this does not mean a full extension). This phase is known by being slower than the second pull, and here is where maximum force values are achieved. This allows the barbell to have its first acceleration, starting from a complete rest while maintaining correct body angles. One of the main differences between the first and the second pulls is that the first is characterised by force, and the second by power (Charniga, 1982; Enoka, 1979; Everett, 2014; Hadi et al., 2012; Hydock, 2001; Torokhtiy, 2022).

In order to facilitate readings and data collection, the First Pull is considered, in this study, from the Lift₁ until the barbell crosses the knee line.

Transition Phase

In order to simplify the study, this phase was purposely left unregistered, because it is the connection between the first and the second pulls, marked by the “re-bend” of the knees (which is also another name to this phase, as well as the “double knee bend”), right after their first maximum extension, where the first pull ends. This happens mainly because of a torso verticalisation which shifts the knees to a more anterior position, causing them to “re-bend”, or flex. It is a very short phase, also known as a non-weighted phase, and where there is a slight deceleration of the barbell (Enoka, 1979; Gourgoulis et al., 2009; Long, 2014).

2. The Second Pull

Phase marked by the maximum knees flexion, caused by the transition phase, at the exact moment they start to extend once again. Second phase ends in the maximum extension of the body, translated by the maximum legs and torso registered extension. This is the phase where the most power is registered. Also, it is just before the maximum extension is achieved (or full extension), that the peak velocity of the barbell is reached (Charniga, 1982; Enoka, 1979; Hadi et al., 2012; Lee et al., 1995; Torokhtiy, 2022).

3. Turnover

This phase begins when the body reaches full extension and continues until the barbell reaches its maximum height, which is the point at which its vertical velocity reaches zero.

This is where the transition from a state of full body muscle contraction is reached (maximum extension), to a highly relaxed state, where the athlete is “self-pulling” himself under the barbell (Gourgoulis et al., 2009; Long, 2014; Verkhoshansky, 1988).

4. Catch

Comprehends the highest vertical point of the barbell (zero speed), followed by a descent, and ends in the first momentum of barbell vertical acceleration, while resting on the athlete's shoulders.

In other words, as soon as the barbell stops moving upwards, gravity will accelerate it downwards, while the athlete moves under it, until he “catches” the barbell, resting it on his ? shoulders in a stable position. The catch phase ends in the moment where the barbell starts a new vertical acceleration. Oscillations (positive and negative) may occur, due to the barbell's weight related elasticity (Gourgoulis et al., 2009; Long, 2014).

5. Recovery

From velocity zero at the final moment of the catch, until full extension of the athlete's body, in final position, completely stabilised (Charniga, 1982; Gourgoulis et al., 2009).

Power Clean Technique Breakdown - Events

These are important instants that occur inside or in between phases. They are important either because they are used to mark the beginning or the end of a phase, or because they are technical details part of a pool of performance points that need to be present, in order to demonstrate a good technique proficiency.

It is important to note that some of the events presented in this study are not based on “textbook technique details”, but on data registered, to precisely determine them in the same way in each lift of each individual.

The events chosen to mark and subdivide the five above presented phases, are the following nine, in order of appearance, in a correct technique:

1. Lift

The first instant that the barbell presents a vertical displacement. First Pull starts to be registered here.

2. Knee Cross

The instant that the barbell crosses the same height as the knees. First Pull register will end here, and Second Pull will begin, with the Transition Phase (unregistered) in between both.

3. Contact

This is the instant at which the bar touches the contact point, theoretically in mid-thigh.

4. Elbow Flexion

This the first moment when the elbow starts flexing. Technically speaking, they flex immediately after or simultaneously with the full extension, but this event is present here before the full extension, for the reasons detailed in the next event.

5. Full Extension

This event is the instant where the athlete's body reaches the maximum leg, hip and torso extension of the current lift. This does not mean that it fully extends. It means that it is the maximum extension achieved.

Full extension is presented here, after elbow flexion, because in theory, the arms should only present flexion after (or simultaneously with) the full extension, in order to fully take advantage of all the acceleration attained by explosively extending the body. Despite this fact, what usually happens is that the maximum vertical velocity achieved by the barbell in the Clean is at a slight instant before the full extension is reached (Hadi et al., 2012; Lee et al., 1995). For this reason, it should be expected to see an elbow flexion just immediately before the full extension is reached, even though it is technically more accurate to describe it as after (or simultaneously with) the full extension is reached.

This is the end of the Second Pull data and the beginning of the Turnover.

6. Barbell Maximum Velocity

Maximum vertical velocity of the barbell. Despite being presented here after the Full Extension, literature shows that it usually occurs slightly before (Hadi et al., 2012; Lee et al., 1995).

7. Catch First

When the barbell vertical velocity reaches zero for the first time or, in other words, at its maximum height after the pull phases.

This is where the Turnover ends and where the Catch phase starts (which includes first and second catch).

8. Catch Second

The second catch event is the moment where the barbell starts a new vertical acceleration. It is the final portion of the Catch phase. Recovery starts here, beginning the legs extension until the final the position is reached.

9. Final Position

This corresponds to the barbell's last velocity zero, when the body is stable, with legs, hips and torso at full extension.

Power Clean - Technical Performance Points

All of the following technical details were taken from Oleksiy Torokhtiy's written technique in the referenced book "Clean Masterclass" (2022), as well as in practical learning through more than 100 hours of seminars.

It is important to state that, in a Power Clean, the goal is not to catch the barbell squatting as low as possible. For that specific purpose, one should seek the most perfect timing possible between contact, maximum velocity and drop. Theoretically, in a full Snatch and Clean, and with a very short margin of error, the barbell's maximum velocity in a pull, thus the barbell maximum height as a consequence is a very strong predictor of one's best lift (Sandau et al., 2021). This means that the top "hat" displayed in the barbell trajectories, as in the green line on figure 7, should be minimal, going in line with the catch of a barbell with as low momentum as possible (Nagao et al., 2019). In the Power Clean, more speed and height should be achieved, because the Catch is supposed to occur above 90° of leg flexion. In turn, this means more explosiveness, and a longer Second Pull.

Start Position

- Feet shoulder-width apart. General consideration for the masses. After a few years of training, individual adaptations to the position of the feet may occur;
- Barbell in contact with the shins, or as close as possible;
- Arms always straight and relaxed;
- Feet pointing slightly outward and knees in the same direction;
- Tense and straight back;
- Shoulders directly above the knees (greater verticality of the torso - more comfortable and stronger position than the Snatch);
- More vertical torso position than in Snatch;
- Look forward.

First Pull

- Feet with weight distributed over the entire base;
- Hips and shoulders rise simultaneously;
- Shoulders in line with knees. The less variation here, the better;

- Main objective is the initial acceleration of the bar, while maintaining proper angles;
- The goal is to give the barbell the first acceleration, since it is responsible for taking a completely still object off the ground. This is the most force productive phase.

Second Pull

- Shoulders should cover the barbell;
- Barbell is as close to the body as possible;
- As the extension progresses, shoulders, arms and knees are in a vertical line;
- Entire foot should be on the ground until the point of contact is reached;
- Contact should occur without a full hip extension and immediately before a full leg extension;
- As soon as contact and explosive extension occurs, relax immediately, rotate elbows forward and start descent;
- This is the most explosive phase of the technique, where the most power is applied.

After Contact, Extension and Catch Position

- Energetic pulling of the elbows upwards and backwards, to guide the rise of the bar after contact in the desired direction (ricochet effect control);
- Elbows should rotate forward as quickly as possible;
- Feet should hit the ground flat for greater contact surface and stability when receiving;
- Barbell rests on deltoids, elbows should present a “high” position;
- Elbows should always be at least parallel. Ideally to “pointing out” and never “pointing in”;
- Recovery, and final position.

Power Clean - Technical Details

Now that we have established the key points for a good technique performance, it is important to add some technical details that can be used to determine whether we are dealing with novices or experienced athletes in the Power Clean

The First and Second Pull should display two different grades of acceleration. The first should be slower. Then, in the Transition Phase, the vertical speed should fall for milliseconds, and then the explosive part should start with a full acceleration until the barbell reaches maximum velocity (Enoka, 1979; Torokhtiy, 2022).

In the first pull, we should see minimum horizontal displacement of the shoulders, related to the knees.

On the Second Pull, while still flat footed until the jump occurs, the athlete should explosively extend legs and hips, make contact with the barbell in mid-thigh, jump and flex the elbows, pointing them up and back.

Before the full extension is reached, the contact should occur. To better understand the contact point importance, it should be pointed out what the Ricochet Effect is. It is also known as the "bouncing bullet" effect, and it occurs when a bullet or projectile strikes a hard, flat surface at a glancing angle and bounces off rather than penetrating the surface. This phenomenon was first described by the French physicist André-Marie Ampère in 1820, who observed that bullets fired at a metal plate at a shallow angle would often ricochet off the plate instead of penetrating it (Ampère, 1820).

According to the Law of Reflection, the "angle of incidence equals angle of reflection", and this is true if neither the projectile nor the surface deforms (Walker, 2014). This means that, if nothing is done, after the contact, the barbell should bounce off the thigh at a similar angle of the incidence one.

Having this in mind, the contact point is a very important and key factor when dissecting both Snatch and Clean techniques. This is where, while maintaining and using correct angles, the athlete can maximise the energy transfer, accumulated by the first and second pull, taking advantage of the ricochet effect. At this point, shoulders should be covering the barbell. After contact and almost simultaneously with the jump, an explosive flexion of the elbows should occur, pulling them up and back, to redirect the barbell's angle to the direction it should go: close to the trunk. If this is not done properly, the barbell is more likely to fly away from the body. In other words, if correctly timed, after the contact the arms will redirect the force vector in the desired direction, as close to the body as possible, through an explosive elbow flexion (Torokhtiy, 2022).

In the path from contact, until the point of full extension, it is expected to see an explosive shoulder displacement from an anterior to a posterior position. In full extension, one should have a close-to straight line between knees, hips and shoulders, with shoulders in a slightly posterior position to the hips and knees, and with hips in a slightly posterior position to the knees. This diagonal line is caused mainly by inertia derived from a heavy load and it should be more accentuated as the weight gets heavier (Torokhtiy, 2022).

After this, the barbell will continue to fly up, now decelerating, until it reaches its maximum height, which is an important factor for a good lift, when related the athlete's height (Ai et al., 2018). This point coincides with Catch First. The latter, and Catch Second are two highly determinant factors of a good performance in weightlifting techniques. It is the culmination of being able to fully and explosively extend the body, and immediately "relax", while going under the barbell, taking as less time as possible. According to Verkhoshansky's technical theory, which states that (...) executing the squat under the barbell after completing the pull in the snatch or the clean involves an instantaneous switching from the extensor muscles from a state of limit tension to a state of complete relaxation (Verkhoshansky, 1988), and it is an important criterion for the assessment of a high level of technique expertise.

The barbell is accelerated up due to mechanical power, through the First and Second Pull. After maximum height is achieved (velocity = 0), gravity will accelerate the barbell down. Being fast going under the weight, after Full Extension, dictates that gravity doesn't have enough time to accelerate the already downwards moving weight into a speed high enough to be problematic for a solid catch. If this time between First and Second Catch is too long, the barbell can be accelerated to a point that its height is so low, that it might be very hard, if not impossible, to catch it successfully. Interestingly, and statistically, the barbell's maximum height is not a key factor in determining a successful lift, but catching the barbell with low momentum is. Therefore, the faster an athlete goes under the barbell and catches it, the more likely they are to be successful in the lift (Nagao et al., 2019).

We need to combine these two facts to better understand the complexity of this. Theoretically, the higher the barbell is raised, the more time the athlete has to go under it. However, it is not possible to keep achieving the same maximum height of the barbell with heavier and heavier weights. An experienced athlete should be capable of going under the barbell using less time and space. They will need less height achieved because they drop faster, catching it with a lower momentum created by gravity. This means they can

successfully be able to lift more weight, and probably with lower maximum barbell velocity, because they need less height to catch the barbell by diminishing the drop movement. In other words, we should expect to see a faster catch even if the barbell is raised less.

The trajectory of the barbell is also a very important criterion to assess the quality of the technique.

Since the shortest distance between two objects is a straight line, it was believed that the barbell path in weightlifting should be as close to vertical as possible. However, barbell's path analysis since the beginnings of weightlifting schools, have shown that novices move the barbell closer to a vertical trajectory but, with a more developed qualification, the trajectory changes more to an "S" shape (Zhekov, 1992). This is also related to the need of moving a weight and balancing the entire system centre of mass from the lift until the final position, while the barbell goes around the body, in a movement in which that external load begins resting on a platform, in front of the athlete's centre of mass, and finishes directly overhead (Bartonietz, 1996). Obviously, it is expected to see more efficiency navigating the barbell around the body as the technique level goes up. This takes us to three specific kinematic factors that should be assessed for the barbell path: (1) an initial rearward movement of the bar during the first pull, (2) a catch position slightly behind the most forward bar position, and (3) an amount of "looping" less than the net rearward horizontal displacement, which again states the importance of the "S" shape movement pattern, but more importantly, which direction should the barbell start to travel first (Winchester et al., 2005).

Due to this evidence, it is expected to measure differences while dissecting the technique, in different levels of expertise.

PROBLEM

How does experienced athletes' technique compare with the one of Medium-Experienced and Unexperienced athletes? There is very little research on unexperienced, medium experienced or non-professional experienced athletes as to how their techniques are expected to vary, as well as when and where.

There is insufficient data to enable you to predict, either what the common mistakes are, or when they will occur. This applies to unexperienced athletes and to medium experienced athletes as well.

There is insufficient information for coaches to accurately address the main difficulties and create a well based progression plan to teach Power Clean to an athlete who has had no contact with it. There is also a lack of information on where it is statistically probable the mistakes to occur, and how to better conduct the improvement of a current user. This affects the athletes learning and improving process and does not help them understand what should happen and when.

Alongside with this, without a better understanding of the problematic areas, and without a deeper knowledge on where to look at, the learning period can get longer than expected, with time spent on learning new abilities and longer periods of refinements.

Objectives

This study aims to provide coaches and athletes with additional tools to improve the learning, teaching and coaching process of the Power Clean technique, starting from the first contact, and proceeding until a solid technique level is achieved.

The aim is to assess the most common problematic key points that occur at different levels of expertise, during various phases and events of a lift.

This involves determining when and where these issues happen and creating tools for improvement. The ultimate goal is to reduce the time needed to achieve a proficient level of expertise and to enable the user to effectively handle workable and trainable loads with better technical details, by making the most of the Power Clean training method.

Hypothesis

- Barbell trajectory is close to a vertical line in novices and evolve to an “S” shape as the experience grows;
- There are two peaks in the velocity of the barbell until full extension. The speed is higher in the second peak, differentiating First and Second Pull clearly;
- Experienced athletes, when compared to medium and experienced ones present:
 1. A more constant start position;
 2. A better shoulder and knee alignment in the First Pull;
 3. Contact of the barbell with thighs will occur with shoulder in an anterior position regarding the barbell;
 4. Flexion of the elbows after contact, and close to full extension;
 5. More pronounced body extension;
 6. Faster catch and with a less horizontal barbell displacement during the Catch phase;
 7. Less horizontal barbell displacement;
- Different body alignments between shoulders, hips and knees in different phases will occur according to different expertise levels;
- Different body movement patterns will exist, depending on the expertise level
- Duration of the Phases will be different between groups;
- Events will occur in different elapsed times, in different expertise levels.

METHODS

Participants

For this study, there were a total of 45 healthy and physically active male participants, divided in three groups of 15, according to their levels of experience in weightlifting, specifically the Power Clean technique. The groups expertise level was named as follows:

- a) Experienced (EXP);
- b) Medium-experienced (ME);
- c) Non-experienced (NOXP).

Inclusion Criteria

- a) Ages ranging from 18 to 45 years;
- b) Male and physically active, performing physical activity for 2 to 3 days per week
- c) Experienced athletes have at least two years of weightlifting practice as part of their training method, for 2 to 3 days per week;
- d) Medium-experienced athletes have between 3 to 6 months of weightlifting practice as part of their training method, for 2 to 3 days per week;
- e) Non-experienced athletes have not had any kind of practical experience with the present technique, except a previous session where the technique is presented and their 1RM is determined;
- f) Applicants must not present any musculoskeletal impairment, which could cause technique deviations beyond normal conditions.

Sample Characterisation

As seen in table 1, there are no statistical differences regarding weight, height or BMI, in between groups. Age presents a significant difference between the medium group and the non experienced one, the medium group being the one with the highest age average.

1RM values are statistically different in all the groups, the experienced being the ones with the highest average; the less experienced, the lower average.

Table 1 - Sample Characterisation, according to expertise: Experienced (EXP), Medium-experienced (ME) and No-experience (NOXP) athletes.

	Sample Analysis - Are there differences?						In between which groups?			
LEVEL	EXP		ME		NOXP		P Value	EXP p Value	MED p VALUE	NO EXP p Value
AGE	média	31,53	média	35,40	média	28,53	p=0,31		NO EXP (p=0,027)	
	dp	6,02	dp	6,88	dp	7,57				
WEIGHT	média	84,27	média	82,67	média	80,00	p=0,604			
	dp	15,37	dp	8,90	dp	9,69				
HEIGHT (m)	média	1,78	média	1,80	média	1,80	p=0.613			
	dp	0,06	dp	0,05	dp	0,08				
BMI	média	26,37	média	25,42	média	24,59	p=0,302			
	dp	3,83	dp	2,47	dp	2,87				
1RM	média	112,33	média	86,33	média	66,00	p<0,001	MED (p=0,001) NO EXP (p<0,001)	NO EXP (p=0,008)	
	dp	23,74	dp	12,46	dp	14,29				

Procedures and Materials

- An informed consent with detailed explanation of the procedures, and data analysis was presented to every participant. All the participants have accepted the terms and fulfil the inclusion criteria, and were evaluated in the Biomechanics Laboratory (LABIOMEPE) of the Faculty of Sport of the University of Porto (FADEUP);
- Three lifts per participant were registered, at 40%, 60% and 80% of their 1RM, previously established;
- The establishment of each 1RM was made 72h prior to the day of the evaluation, with a 3 minute general warm up in a Concept 2 rowing machine, free rowing, with a low to medium individual intensity. Then, each individual gradually added weight to a standard 20kg Olympic barbell, with 28mm of diameter; with a set of markers to register movement, always guaranteeing a minimum of 3 minutes of rest and a maximum of 5 in between attempts, until their best lift was registered;
- A minimum of three minutes of rest was mandatory, due to the evidence which suggests that if it is less, the proficiency of the technique might suffer so, to reduce technical biases, 3 minutes was the minimum (Ammar et al., 2020). The 40%, 60% and 80% was based on this lift named as “1RM” in this study;
- In the evaluation day, the same general warm up was performed, and then each individual loaded progressively the barbell until the 40%. Every lift was performed with a minimum and a maximum of 3 and 5 minutes of rest, respectively.

Figure 2 - Barbell layout and markers placement.



Statistical procedures

The results were expressed as mean (standard deviation) for descriptive analysis of the different dependent variables - phases, events and alignments, across groups of intensity (40%, 60% and 80%) and groups of expertise (EXP, ME, NOXP). The data followed normal distribution and to test differences between means, across all groups, one-way ANOVA was applied, with significance value of $p \leq 0.05$.

The Bonferroni procedure was done as a multiple comparison between group post-hoc test.

All statistical analyses were performed with the IBM SPSS. Statistics (version 25, Chicago, USA), for the value of $p < 0.05$.

Movement Analysis

A hybrid motion capture system, comprising markerless and marker-based cameras, was used to capture participants Power Clean movement. This was obtained by collecting simultaneously and synchronously, in the Qualisys Track Manager software (Qualisys AB, Sweden), data from a markerless and marker-based motion capture systems. The markerless system was used to record the participants body movement, and it was

composed by 8 Miquis Video cameras (Qualisys AB, Sweden) operating at 100 Hz and 720p resolution. The marker-based system was composed by 12 Oqus cameras (Qualisys AB, Sweden) operating at 200 Hz. A set of 12 mm retro-reflective markers was placed on the barbell in both edges, in order to model the bar orientation and movement during the task. Simultaneously, ground reaction forces data was collected in synchrony with the motion capture system at a frequency of 1000 Hz.

The markerless video data was then processed on Theia v2022.1.0.2309 (Theia Markerless, Canada) in order to detect a full body with 3 degrees of freedom segments. The resulting detected movement were then exported to Visual3D v.2021.11.3 (C-Motion, USA) where further calculations were performed.

This software was also used to model the bar as a kinematic segment, and the markerless and marker-based data were merged.

Pipelines Description

1. Down sample Targets

Loads the Coordinate 3 Dimensions (C3D) files containing the marker trajectories into the Compressed Poser Camera Set (CMZ) file and resamples the target information to 100 hertz (Hz) to match that of the markerless movements.

It then exports a set of American Standard Code for Information Interchange (ASCII) files that must be named manually. Each file contains the resampled target information.

Each file has to have the Owner Filename manually changed to match that the motion file present in the CMZ workspace.

2. Filter Targets

Once the ASCII files have been prepared, this pipeline will load the targets into the appropriate motion files and perform a 6 Hz lowpass filtering of trajectories. A hybrid motion file will be the result.

3. Event Detection

Before execution of the pipeline, manually create a “BEGIN” and “STOP” event approximately to the corresponding times of movement initiation and ending. This will help the detection process by creating analysis boundaries.

When there was a need to analyse data that was divided in two sides (left and right), the right side was chosen by default for consistency.

The routine will perform the detection of relevant events, namely:

- **Start:** The first instant that Ground Reaction Forces (GRF) increases 20 Newtons (N) over the total weight (body + barbell);
- **Lift:** The first instant that the right side of the barbell (R_Bar) presents a vertical displacement;
- **Knee Cross:** The instant that the bar (R_Bar) crosses the same height as the right knee (R_Knee);
- **Contact:** the instant in which the bar (R_Bar) touches the thigh, as measured by the inflexion points on the barbell's anterior-posterior (AP) direction;
- **Full Extension:** the instant where the right shoulder (R_Sh) and right ankle (R_Ak) have the most vertical alignment (Z axis), between the Contact and Catch First;
- **Elbow Flexion:** the moment when the right elbow (R_Elb) starts flexing after Knee Cross, as detected by the ascending zero crossing of the first derivative of angle (angular velocity) of the elbow;
- **Bar Maximum Velocity:** maximum registered vertical velocity of the bar (R_Bar);
- **Catch First:** when the barbell (R_Bar) velocity crosses zero-value before bar rotation and after maximum velocity. This is the moment when the R_Bar reaches the highest point before the catch second. This is not the same as maximum height attained in the Final Position, and should not be confounded;
- **Catch Second:** when the barbell (R_Bar) velocity crosses zero-value after the rotation of Catch First;
- **Final Position:** after raising the centre of mass, and achieving maximum bar (R_Bar) height. This corresponds to the barbell's final velocity zero

4. Metrics - Phase Duration

Each phase duration is calculated in terms of absolute (seconds) and normalised (0 to 1) duration. Normalisation (NORM) is performed by dividing the absolute phase duration by the total duration of the task (Lift to Final Position).

- **First Pull:** from Lift to Knee Cross;
- **Second Pull:** from Knee Cross to Full Extension;
- **Turnover:** from Full Extension to Catch First;
- **Catch:** From Catch First to Catch Second;
- **Recovery:** from Catch Second to Final Position.

5. Metrics - Event Instances

Important events that occurs within Phases, from Lift to Final Position, are calculated as follows: The absolute (seconds) and normalised (0 to 1) values are presented. The instance of occurrence corresponds to the time passed since Lift in percentage.

Example: if Knee Cross occurs at 0,57s it will correspond to 28,5% if the full movement presents a duration of 2 seconds.

6. Metrics - Bar Trajectory

This pipeline removes the offset of the barbell position in the AP, medial-lateral (ML) and Vertical (VERT) directions so that the displacement can be calculated more easily.

There is a signal for each corrected direction, but each signal has 3 planes of movement. Only the X (ML), Y (AP) and Z (Vert) have been corrected in the corresponding signals.

The signals are normalised to the participants' height.

The pipeline then calculated the maximum and minimum displacement on the AP and vertical direction, between Lift and Final Position.

Note: Since vertical displacement is always positive, the minimum is the value of the barbell is at Lift. This means that it will always be zero in either ABS or NORM form.

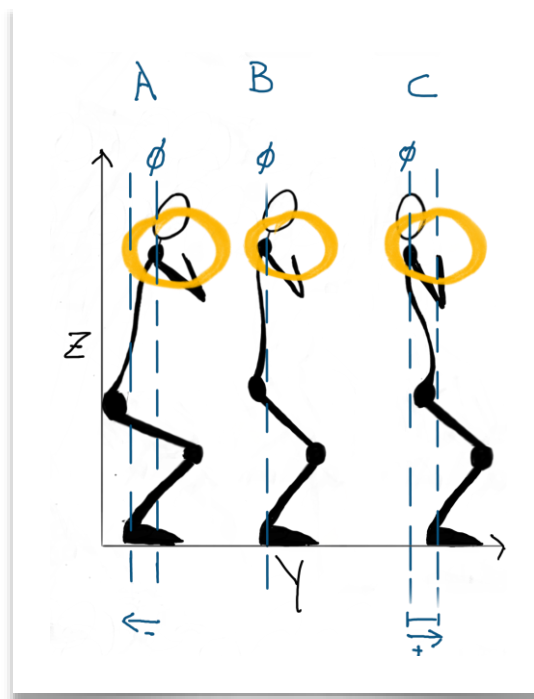
7. Metrics - Alignment

Calculates the distance between the shoulder (R_Sh) and Ankle (R_Ak) alignment in two anatomic planes during each of the significant events previously detected.

Value Interpretation

- Y axis (AP): negative values indicates that the shoulder position is anterior regarding the ankle (figure 3, A). Positive values indicates that the shoulders are vertically behind the ankles (figure 3, C). If the value is zero, it means that shoulder and ankle are aligned vertically (figure 3, B).
- Z axis (vertical): always negative, indicates purely vertical distance, in meters, from shoulder to the ankle.

Figure 3 - Shoulder and Ankle alignments.

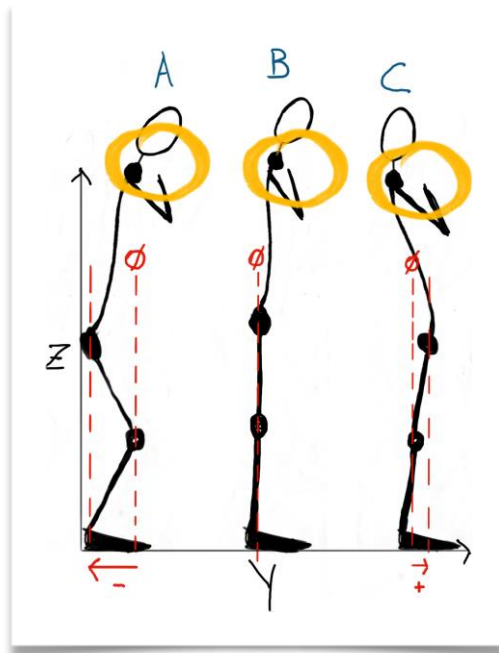


Similarly, the distance between the right hip (R_Hip) and the knee (R_Kn) joint centres are calculated.

- Y axis (AP): negative indicate knees are forward in relation to the hip (figure 4, A). Positive values indicate that the hip has surpassed the knees (figure 4, C). If the value is zero, it means that the R_Hip and R_Kn are vertically aligned (figure 4, B).
- Z axis (Vert): always positive.

Small value indicate that the hip and knee are almost at the same level (e.g. seated on a chair), and higher values mean that the hip is above the knee.

Figure 4 - Hip and Knee alignments.



RESULTS

Data collected for analysis in this study and its statistics relevance has been transferred to the three tables below - tables 2, 3 and 4. The tables 2 and 3 have the same phases and events breakdown, as detailed in the Review topic. The table 4 comprises the alignments distances horizontally and vertically in the relevant events.

To facilitate readings, statistically equal phases, events and alignments have been highlighted in green.

It is important to clarify that a Power Clean is a fast movement. It can take around two to three seconds from Lift until Final Position. This means that Phases and Events, despite being quite numerous, happen in a consecutive and fast way.

Phases - Table 2 - General Analysis

- Considering only the duration of each phase, 4 of the 5 phases are significantly different in the 40% lift, 3 of the 5 phases are significantly different in the 60% lift and 4 of the 5 in the 80% lift;
- In the 40% lift, significant differences are found in every phase, except for the Turnover;
- In the 60% lift, the differences are in the Second Pull, Catch and Recovery;
- In the 80% one, the exception is the First Pull, being the only one in which there are no differences to register;

Phases - Table 2 - Specific Analysis

First Pull

- As the load gets higher, differences in the duration of the First Pull reduces, being statistically more similar. The 40% lift has a p value of $<0,001$, the 60% lift presents a $p=0,051$ and a $p=0,139$ is shown in the 80% one;
- In the First Pull alone, the medium group is the more consistent one having 16% of the duration of the full movement dedicated to this phase, with less than 0,20% of time variation;

- Experienced ones had an average small variation, of just 1,77%, in the most different duration;
- The unexperienced group varied from 27,06% to 18,78%, which is a 8,28% variation, in the most different duration.

Second Pull

- It presents statistically duration differences in all of the three loads;
- Considering the total duration of the movement, the EXP presents a shorter Second Pull, in relation to the First Pull.;
- As the weight increases, this difference decreases, being 3.31%, 1.42% and 0.93% for the 40%, 60% and 80% lift, respectively. Despite the decrease, Second Pull is consistently faster in average, in each lift of the EXP;
- The above is not true in the ME and NOXP. Both ME and NOXP presents a faster Second Pull only in the 40% lift. In the 60%, despite being a small difference, the ME has a 0.77% slower Second Pull and the NOXP this value goes to 1.64%;
- Bigger differences are found in the heaviest lift, with a 1.87% and 4,67% slower Second Pull, for the ME and NOXP, respectively.

Turnover

- Turnover, by opposition to the First Pull, increases differences in duration as the load gets higher, becoming statistically significant in the 80% lift, with a $p=0,020$, where the NOXP the group which more time expends in this task, using 18.12%, in contrast with 13.09% and 12.95% for the EXP and ME respectively.

Catch

- Catch and Recovery Phases presents a significantly different duration in the three percentages lifted in at least one of the three groups;
- Catches present a p value of 0.013 and 0.020 in the 40% and 80% lift and 0.000 in the 60% one. Also, they represent always less than 10% of the total movement time in the EXP and ME, with an exception for the 60% lift of the ME, that has 11.88% of time. For the NOXP, Catches represent values from 11.84% up to 19.21%, and without a pattern to establish with the load increase;

- Recoveries present a $p=0.000$ in the three loads;
- EXP has the fastest Catch phase between groups, in every load, even if comparing between loads. The longest Catch of this group, which is 9.5% of the total movement time, is shorter than the shortest of any other group, which is a 9.7% in the ME;
- EXP demonstrates decreases in the duration of the Catch, along with increases in loads. They spend 9.5% of total time in Catch, for the 40% lift, 8.35% in the 60% lift and 7.81% in the 80% one;
- ME also show a tendency to decrease time spent in Catch, considering the full movement. They start at 11.88% in the 40% and the 60% and 80% lifts Catch took 9.7% of the total movement time;
- NOXP has the longest durations in this phase, and are inconsistent. 16.01%, 19.21% and 11.84% for the 40%, 60% and 80% lifts, respectively.

Recovery

- The NOXP presents significant shorter durations in the Recovery phase. Their time range goes from 21.54% to 28.2%;
- The ME goes from 42.57% to 45.02%;
- EXP ranges from 36.47% to 41.88%.

Table 2 - Phases duration comparison, for the 5 phases, presented in percentages, for each load (40%, 60% and 80%), between expertise levels: Experienced (EXP), Medium-experienced (ME) and No-experience (NOXP) athletes.

DO PHASES HAVE THE SAME DURATION BETWEEN GROUPS? LOADED AT 40% 60% 80% of a 1RM													
% of RM	40%				60%				80%				
LEVEL	EXP	ME	NOXP	BTW GROUPS 40%	EXP	ME	NOXP	BTW GROUPS 60%	EXP	ME	NOXP	BTW GROUPS 80%	
FIRST_PULL	média 19,23%	média 16,04%	média 27,06%	$p<0,001$	média 21,00%	média 16,08%	média 21,12%	$p=0,051$	média 19,33%	média 16,22%	média 18,78%	$p=0,139$	
	dp 5,00%	dp 3,45%	dp 10,85%		dp 5,27%	dp 4,57%	dp 8,21%		dp 4,96%	dp 4,22%	dp 4,20%		
SECOND_PULL	média 15,92%	média 15,92%	média 21,86%	$p=0,010$	média 19,58%	média 16,85%	média 22,76%	$p=0,017$	média 18,40%	média 18,09%	média 23,45%	$p=0,005$	
	dp 3,75%	dp 3,75%	dp 7,93%		dp 4,00%	dp 4,65%	dp 7,12%		dp 4,46%	dp 4,15%	dp 5,71%		
TURNOVER	média 13,47%	média 12,24%	média 13,70%	$p=0,734$	média 14,60%	média 12,36%	média 14,71%	$p=0,389$	média 13,09%	média 12,95%	média 18,12%	$p=0,002$	
	dp 4,37%	dp 2,90%	dp 7,86%		dp 4,40%	dp 2,91%	dp 7,39%		dp 2,74%	dp 2,87%	dp 6,20%		
CATCH	média 9,50%	média 11,88%	média 16,01%	$p=0,013$	média 8,35%	média 9,70%	média 19,21%	$p=0,000$	média 7,81%	média 9,70%	média 11,84%	$p=0,020$	
	dp 6,84%	dp 4,38%	dp 5,99%		dp 2,95%	dp 4,34%	dp 8,63%		dp 2,03%	dp 3,97%	dp 4,81%		
RECOVERY	média 41,88%	média 42,57%	média 21,54%	$p=0,000$	média 36,47%	média 45,02%	média 22,21%	$p=0,000$	média 41,37%	média 43,04%	média 28,20%	$p=0,000$	
	dp 13,43%	dp 6,85%	dp 11,86%		dp 12,17%	dp 10,15%	dp 11,44%		dp 11,79%	dp 8,63%	dp 9,70%		

Events - Table 3 - General Analysis

- Considering the moments or instants where the 7 events of the table 3 happen, in regards to the percentage of elapsed time since the Lift, it is on the 80% lifts that more events happen in statistically similar times. Three out of seven events have no differences in timing in this lift: Knee Cross, Contact and Barbell Maximum Velocity;
- Knee Cross also happens in the same timing in the 60% lift, which was expected because it is coincident with the First Pull phase duration, as shown in the previous phases topic;
- Barbell Maximum Velocity is attained statistically in the same instant only in the 80% lift;
- In the 40% lift there are no statistical similarities in any event timing;
- In the 60% lift the exception is the Knee Cross. Every other event is statistically different.

The timings of a single event are not very useful to obtain good information. They should be looked at in a perspective of when they happen in relation to the previous and the following one, or in exceptional cases, in relation to a more distant event, as explained in the next topic. For this matter, in the Specific Analysis, found below, each event will be analysed having this into account.

The events will be presented and analysed in order of appearance of a theoretical good technique proficiency, with the exception of the Barbell Maximum Velocity, which has already been shown to be correct to appear slightly before Full Extension event. This means that one event is supposed to occur before the following one.

Events - Table 3 - Specific Analysis

Knee Cross

- This event has the same values as the First Pull duration, which is the percentage time from the lift until the Knee Cross phase, which means that its timing was already analysed in the previous topic;

Contact and Elbow Flexion

- Data from table 3 has to be crossed with data extracted from the observation in Visual3D of the 135 lifts (3 groups and 3 lifts per group of 15 people) specifically in regards to the R_Bar Y axis, which accurately determine whether or not a Contact point exists;
- According to the above, the following subjects and lifts did not present an effective Contact event, which means that the barbell did not have physical contact with the thigh, thus not using an important part of the technique:

ID23 - 40%, 60% and 80% lifts

ID24 - 40%, 60% and 80% lifts

ID31 - 40% lift

ID32 - 40% and 60% lifts

ID34 - 40%, 60% and 80% lifts

ID35 - 40%, 60% and 80% lifts

ID39 - 40% and 60% lifts

ID40 - 40% and 60% lifts

ID44 - 40%, 60% and 80% lifts

- These latter subjects are 2 out of 15 of the ME and 7 out of 15 of the NOEXP;
- In the EXP, Contact happens in average always before the Elbow Flexion, as it should in a good technique. It occurs before Elbow Flexion 0.74%, 2.22% and 4.58% in the 40%, 60% and 80% lifts, respectively;
- This timing shown in the EXP is not visible in the two other groups. Elbow Flexion occurs in average always before the Contact, and in the 60% and 80% lifts of the ME and NOXP, it occurs even before the Knee Cross event. Even though in some cases it is close to the timing of the Knee Cross, it is still distant of the timing of the Contact;
- It important to point that some subjects of the ME and NOXP start the Elbow Flexion as soon as the Lift occurs, which was observed in the same data treatment software.

Elbow Flexion and Barbell Maximum Velocity

- Timing of the Elbow Flexion related to the Barbell Maximum Velocity is more distant than it was expected in the Experienced group. It occurs 6.71%, 7.45% and 5.61% before, in the 40%, 60% and 80% lift, respectively;
- The comparison here for the ME and NOXP doesn't provide useful information, since the majority of Elbow Flexions have happened before the Knee Cross event, and the one who don't, have occurred before contact;
- Regarding Barbell Maximum Velocity, it only presents statistical similarities in the time when it occurs, considering the full movement of each group, in the 80% lift;
- The group who achieves it, in average, always sooner, is the ME and the one who presents it later is the NOXP. For the lifts of 40%, 60% and 80%, 32.37%, 31.95% and 33.21% of total time has elapsed in the movement for the ME. As for the NOXP, 44.45%, 40.18% and 39.20% of the total time was needed to achieve maximum barbell velocity. EXP was the group in between these values.

Barbell Maximum Velocity and Full Extension

- By looking at the Full Extension event alone, there are statistical differences in the timing where it occurs between at least two of the three groups, and the most different is the NOXP;
- NOXP presents the bigger time difference between these two events. 4.84%, 3.84% and 3.44% for the 40%, 60% and 80% lifts, respectively;
- EXP presents 0,38%, 1.57% and 1.39%, where ME shows 0.94%, 0,98% and 1.1%, for the same lifts.

Full Extension and Catch First

In every lift and in every load, there are significantly statistical differences between at least one of the groups in the Catch First event;

p values vary from <0.001 to $=0.002$, and the group where the instant when it occurs is the latest, is the NOXP, in every lift;

When comparing the Full Extension to the Catch First, which corresponds to the Turnover Phase, thus combining the two events, two out of the three lifts have the same duration.

The heavier is the one who shows differences in at least one of the groups. Again, as stated above, the slowest is the NOXP.

Catch First and Catch Second

- Both events present significantly different results. The first has already been referred to above. The second follows the same line of action, where at least one of the three groups is different, and the one where this event occurs later is the NOXP;
- The combination of Catch First and Catch Second corresponds to the Catch Phase. In this case, the difference of timings between them will correspond to the duration of this phase, already reviewed in the previous table.

Table 3 - Events instants occurrence comparison, for 7 events, presented in percentages, for each load (40%, 60% and 80%), between expertise levels: Experienced (EXP), Medium-experienced (ME) and No-experience (NOXP) athletes.

DO EVENTS OCCUR AT SIMILAR INSTANTS BETWEEN GROUPS? LOADED AT 40% 60% 80% OF A 1RM													
% of RM	40%				60%				80%				
LEVEL	EXP	ME	NOXP	BTW GROUPS 40%	EXP	ME	NOXP	BTW GROUPS 60%	EXP	ME	NOXP	BTW GROUPS 80%	
KNEE CROSS	média 19,23%	média 16,04%	média 27,06%	p<0,001	média 21,00%	média 16,08%	média 21,12%	p=0,051	média 19,33%	média 16,22%	média 18,78%	p=0,139	
	dp 5,00%	dp 3,45%	dp 10,85%		dp 5,27%	dp 4,57%	dp 8,21%		dp 4,96%	dp 4,22%	dp 4,20%		
CONTACT	média 27,32%	média 23,48%	média 35,94%	p<0,001	média 29,34%	média 22,32%	média 31,18%	p=0,002	média 26,15%	média 23,26%	média 27,72%	p=0,164	
	dp 5,81%	dp 6,08%	dp 10,09%		dp 7,10%	dp 5,80%	dp 7,04%		dp 7,30%	dp 5,55%	dp 6,15%		
ELBOW FLEXION	média 28,06%	média 18,64%	média 28,59%	p=0,007	média 31,56%	média 16,00%	média 19,95%	p<0,001	média 30,73%	média 13,70%	média 17,45%	p<0,001	
	dp 6,14%	dp 7,12%	dp 12,94%		dp 6,50%	dp 8,04%	dp 13,33%		dp 7,59%	dp 11,92%	dp 14,92%		
FULL EXTENSION	média 35,15%	média 33,31%	média 49,29%	p<0,001	média 40,58%	média 32,93%	média 44,02%	p=0,003	média 37,73%	média 34,31%	média 42,64%	p=0,020	
	dp 6,01%	dp 5,01%	dp 12,31%		dp 7,55%	dp 7,21%	dp 10,07%		dp 9,00%	dp 6,90%	dp 7,31%		
BAR MAX VELOCITY	média 34,77%	média 32,37%	média 44,45%	p<0,001	média 39,01%	média 31,95%	média 40,18%	p=0,023	média 36,34%	média 33,21%	média 39,20%	p=0,136	
	dp 6,17%	dp 6,09%	dp 10,96%		dp 7,56%	dp 7,03%	dp 10,52%		dp 8,48%	dp 6,72%	dp 8,73%		
CATCH FIRST	média 48,62%	média 45,55%	média 61,61%	p<0,001	média 55,18%	média 45,29%	média 58,58%	p=0,002	média 50,82%	média 47,27%	média 63,31%	p<0,001	
	dp 8,95%	dp 6,74%	dp 11,56%		dp 11,13%	dp 9,19%	dp 9,08%		dp 11,27%	dp 9,28%	dp 11,06%		
CATCH SECOND	média 58,12%	média 57,43%	média 78,34%	p<0,001	média 63,53%	média 54,98%	média 77,79%	p<0,001	média 58,63%	média 56,96%	média 73,97%	p<0,001	
	dp 13,43%	dp 6,85%	dp 11,66%		dp 12,17%	dp 10,15%	dp 11,44%		dp 11,79%	dp 8,63%	dp 9,29%		

Body Alignments - Table 4 - General Analysis

- In a wide look most of the differences found in the full movement were registered in the Catch Phase, where systematic differences between at least one of the groups are found;

- In the Lift, or starting position, differences can only be registered in 2 out of 14 possible measurements. The NOXP is the one who presents the greatest difference;
- The same happens in the Knee Cross event, where in 1 of the 14 measurements the NOXP group presents statistical differences;
- Statistically speaking, no differences can be found in any alignment regarding Contact;
- Maximum velocity of the barbell was attained with only 3 out of 14 alignments with statistical differences in at least one of the groups, all of which in the horizontal displacement of the shoulder. Here, the distances differences impact both ME and NOXP groups, that display a more vertical position, in opposition to a more diagonally positioned body;
- Differences start to be more apparent from Full Extension onwards. Here, 5 out of 12 alignments are different, in at least one of the groups. In this case, ME present a small deviation from EXP and NOXP present a deviation from the ME. These deviations translate into a less explosive extension;
- Both Catch First and Catch Second present significant differences in 11 out of 12 body alignments;
- As expected, Final Position does not present a great statistical relevance. Only 1 out of 12 body alignments is significantly different in at least one of the three groups;
- Despite the data above, smaller differences do exist in each event, and even though they might not be significant, the combination of several little differences in alignments can lead to a different body posture. This will be further analysed.

Body Alignments - Table 4 - Specific Analysis

Lift

- For the EXP there was a 1cm variation in hips height and shoulder height, from the 40% lift to the 60% one. When going to the 80% lift, there was another rise of 1cm of hips only;
- A variance of 7cm is seen in the distance between lifts on the shoulders to ankles distance in the NOXP, as well as a 4cm height difference between hips and knees.

Generally speaking, in the NOXP groups, there is no pattern to establish in the set-up position;

- Shoulder to ankle height has a $p=0,019$ and hip to knee a $p=0.036$, when comparing groups. The NOXP is the most different. The first p value equals a 6cm lower position and the second one a 4cm lower position, in comparison to the other two groups.

Knee Cross

- Statistically significant differences can be found in just one of the twelve alignments. It is in the horizontal shoulder displacement, with a p value of 0.032;
- Despite the fact above, EXP display a constantly larger distance between shoulders and ankles, when the Knee Cross was registered, which translates into a more upright position when the event occurs.

Contact

- From a statistic point of view, no significance is observed in this event;
- However, the combination of alignments suggests a more vertical torso position of the EXP in Contact, and a slight more bent leg position, when comparing to the two other groups.

Barbell Maximum Velocity

- Statistical significances between at least one of the groups can only be found on the shoulder horizontal displacement;
- p values displayed are $=0.003$, <0.001 and <0.001 , for the three lifts, respectively;
- For the 40%, 60% and 80% lifts, EXP shoulders are 7cm, 10cm and 11cm behind the ankles. ME are 2cm, 3cm and 6cm. NOXP are 2cm, 2cm and 1cm in front of the ankles;
- The remaining body alignments are statistically the same.

Full Extension

- In line with the differences found in the latter, in this event, shoulder displacement also presents significant differences, with similar magnitudes and readings in the three lifts;
- The main difference here is that exceptionally the NOXP shift the shoulders to a posterior position, in relation to the ankles. This happens in two of the three lifts, being 1cm in the 60% lift and 4cm in the 80% lift;
- There are significant differences in the horizontal distance between hips and knees in the 60% and 80% lifts. The Experienced group is the one who displays a less aligned hip and knee, having the hips more posterior than the knees 5cm and 6cm, respectively. The no-experienced group displays a more aligned hip and knee. Three centimetres in both lifts.

Catch First

- Significant differences are found between at least one of the groups in all alignments and lifts, except for shoulder displacement in the 80% lift;
- It has to be pointed out that this event refers to the barbell maximum height, or velocity zero, and it is the primary preparation for the Catch Second. Alongside, experienced ones always perform a “jump” or a two feet take off, as a consequence of the explosiveness expressed in the Second Pull, effectively losing contact with the ground. This is not true in every ME and it is not true in most NOXP. The Catch First should be almost simultaneous with feet reception to the ground, when it happens;
- Height differences between shoulders and ankles, in relation to EXP and NOXP, vary from 10cm to 11cm, being lower in the EXP. Considering that in the previous event there were no significant differences in heights, this translates into a faster drop movement;
- Differences from EXP to ME vary from 3 to 4cm, which is not considerable, looking at the heights alone;
- As expected, the same happens with the height distance of the hips in relation to the knees, where there are 6, 7 and 8cm of difference in between EXP and NOXP;
- Going in line with the above, hips are always in a more posterior position in the EXP than in the NOXP;

- Between these two, it is the ME the one which supports, once again that the Experienced group is at one end of the proficiency, while the Non-Experienced is at the other end, with the Medium Experienced somewhere in between.

Catch Second

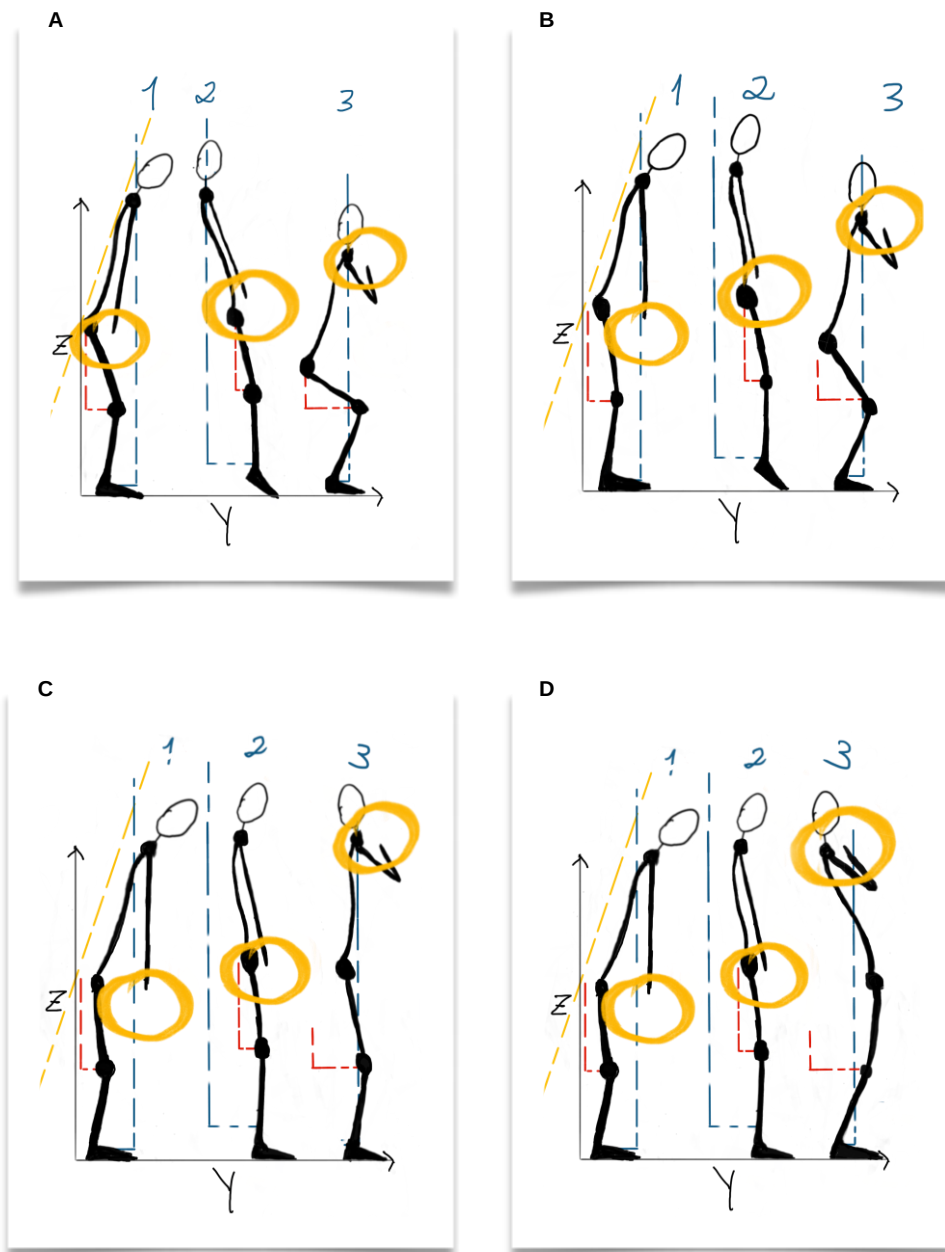
- This is the final Catch position, where a solid body position is a must. Going in line with Catch First, significant differences are found between at least one of the groups in all alignments and lifts, except for shoulder displacement, in the 80% lift. Despite this, it is important to note that all of the differences relate to how much anterior the shoulders are in relation to the ankles, and EXP is the one who always displays a more anterior position;
- Experienced group catch heights are progressively lower, as the loading increases;
- To present a solid catch, the following should be checked: 1) shoulders should be anterior in relation to the ankles; 2) hips should be posterior in relation to the knee.
- According to the above, and despite the fact that the average distances do not display this, some of the NOXP have shown a critical error in the Catch Second:
 - a) In the 40% lift, 4 out of 15 subjects presented hips more forward than the knees, and 2 of these also had the shoulders behind the ankles;
 - b) In the 60% lift, 3 out of 15 subjects presented hips more forward than the knees, of which 1 also had the shoulders behind the ankles. He was one of those two who had previously displayed the same error;
 - c) In the 80% lift, 4 out of 15 presented hips more forward than the knees, of which 1 also had the shoulders behind the ankles, error that he made for the first time.
- This shows that 5 out of 15 No-Experienced athletes do not have the proper form to receive a barbell on the shoulders. This is also true for the NOXP, but an inconsistency can be noticed in the averages of the ME, where the catch height is not directly related to the weight alone;
- Considering the shoulders to ankles height from Full Extension to Catch Second in the 80% lift, the Experienced group has a 28cm difference, while the ME has 23cm and the NOXP 14cm.

Table 4 - Body Alignments comparison in all phases and events, for the alignments between shoulder/ ankle, and knee/ hip, in horizontal and vertical plane. Presented in meters, for each load (40%, 60% and 80%), between expertise levels: Experienced (EXP), Medium-experienced (ME) and No-experience (NOXP) athletes.

			ARE BODY ALIGNMENTS THE SAME, BETWEEN GROUPS? LOADED AT 40% 60% 80% OF A 1RM															
			% of RM		40%				60%				80%					
			LEVEL	EXP	ME	NOXP	BTW GROUPS 40%	EXP	ME	NOXP	BTW GROUPS 60%	EXP	ME	NOXP	BTW GROUPS 80%			
FIRST PULL	LIFT	Shoulder and Ankle Alignment	Horizontal Plane	media -0.21 dp 0.04	media -0.19 dp 0.03	media -0.23 dp 0.06	p=0.065	media -0.21 dp 0.05	media -0.20 dp 0.03	media -0.23 dp 0.04	p=0.134	media -0.21 dp 0.04	media -0.20 dp 0.03	media -0.23 dp 0.04	p=0.152			
			Vertical Plane	media -0.83 dp 0.03	media -0.83 dp 0.04	media -0.77 dp 0.11	p=0.019	media -0.84 dp 0.03	media -0.84 dp 0.04	media -0.84 dp 0.05	p=0.997	media -0.84 dp 0.03	media -0.84 dp 0.04	media -0.84 dp 0.05	p=0.808			
		Hip and Knee Alignment	Horizontal Plane	media -0.32 dp 0.03	media -0.34 dp 0.03	media -0.34 dp 0.06	p=0.535	media -0.32 dp 0.03	media -0.33 dp 0.04	media -0.30 dp 0.08	p=0.254	media -0.32 dp 0.03	media -0.32 dp 0.03	media -0.31 dp 0.05	p=0.721			
			Vertical Plane	media 0.19 dp 0.04	media 0.18 dp 0.05	media 0.20 dp 0.07	p=0.757	media 0.20 dp 0.04	media 0.20 dp 0.04	media 0.24 dp 0.05	p=0.036	media 0.21 dp 0.04	media 0.21 dp 0.04	media 0.23 dp 0.05	p=0.422			
	KNEE - CROSSES	Shoulder and Ankle Alignment	Horizontal Plane	media -0.22 dp 0.03	media -0.21 dp 0.03	media -0.21 dp 0.06	p=0.816	media -0.22 dp 0.03	media -0.22 dp 0.03	media -0.22 dp 0.04	p=0.931	media -0.24 dp 0.03	media -0.24 dp 0.03	media -0.24 dp 0.04	p=0.975			
			Vertical Plane	media -1.06 dp 0.04	media -1.04 dp 0.05	media -1.02 dp 0.06	p=0.203	media -1.05 dp 0.04	media -1.05 dp 0.07	media -1.02 dp 0.05	p=0.252	media -1.05 dp 0.04	media -1.04 dp 0.05	media -1.03 dp 0.05	p=0.278			
		Hip and Knee Alignment	Horizontal Plane	media -0.19 dp 0.03	media -0.20 dp 0.04	media -0.22 dp 0.04	p=0.032	media -0.18 dp 0.03	media -0.18 dp 0.04	media -0.20 dp 0.05	p=0.213	media -0.17 dp 0.03	media -0.17 dp 0.03	media -0.18 dp 0.05	p=0.540			
			Vertical Plane	media 0.33 dp 0.03	media 0.33 dp 0.03	media 0.33 dp 0.05	p=0.681	media 0.34 dp 0.02	media 0.35 dp 0.03	media 0.33 dp 0.04	p=0.146	media 0.35 dp 0.02	media 0.36 dp 0.02	media 0.35 dp 0.05	p=0.632			
SECOND PULL	CONTACT	Shoulder and Ankle Alignment	Horizontal Plane	media -0.11 dp 0.04	media -0.13 dp 0.04	media -0.15 dp 0.05	p=0.162	media -0.13 dp 0.03	media -0.17 dp 0.04	media -0.16 dp 0.05	p=0.137	media -0.16 dp 0.04	media -0.17 dp 0.04	media -0.18 dp 0.05	p=0.722			
			Vertical Plane	media -1.25 dp 0.06	media -1.22 dp 0.12	media -1.23 dp 0.08	p=0.649	media -1.23 dp 0.09	media -1.21 dp 0.09	media -1.23 dp 0.09	p=0.775	media -1.20 dp 0.09	media -1.20 dp 0.08	media -1.20 dp 0.11	p=0.979			
		Hip and Knee Alignment	Horizontal Plane	media -0.14 dp 0.04	media -0.16 dp 0.04	media -0.15 dp 0.04	p=0.524	media -0.16 dp 0.03	media -0.18 dp 0.03	media -0.15 dp 0.08	p=0.183	media -0.16 dp 0.03	media -0.17 dp 0.03	media -0.15 dp 0.03	p=0.060			
			Vertical Plane	media 0.35 dp 0.03	media 0.36 dp 0.03	media 0.37 dp 0.03	p=0.347	media 0.35 dp 0.03	media 0.36 dp 0.04	media 0.36 dp 0.04	p=0.480	media 0.35 dp 0.02	media 0.35 dp 0.02	media 0.36 dp 0.05	p=0.196			
	BAR - MAX - LEVEL	Shoulder and Ankle Alignment	Horizontal Plane	media 0.07 dp 0.03	media 0.02 dp 0.07	media -0.02 dp 0.08	p=0.003	media 0.10 dp 0.02	media 0.03 dp 0.07	media -0.02 dp 0.07	p=0.001	media 0.11 dp 0.04	media 0.08 dp 0.04	media -0.01 dp 0.08	p=0.001			
			Vertical Plane	media -1.38 dp 0.05	media -1.39 dp 0.05	media -1.35 dp 0.06	p=0.390	media -1.38 dp 0.06	media -1.38 dp 0.05	media -1.36 dp 0.07	p=0.281	media -1.38 dp 0.05	media -1.35 dp 0.05	media -1.37 dp 0.08	p=0.598			
		Hip and Knee Alignment	Horizontal Plane	media -0.07 dp 0.03	media -0.07 dp 0.03	media -0.08 dp 0.06	p=0.650	media -0.07 dp 0.03	media -0.07 dp 0.03	media -0.08 dp 0.04	p=0.966	media -0.07 dp 0.03	media -0.08 dp 0.02	media -0.06 dp 0.04	p=0.897			
			Vertical Plane	media 0.38 dp 0.03	media 0.39 dp 0.03	media 0.39 dp 0.03	p=0.388	media 0.38 dp 0.02	media 0.39 dp 0.02	media 0.39 dp 0.02	p=0.253	media 0.39 dp 0.02	media 0.39 dp 0.02	media 0.39 dp 0.05	p=0.881			
TURN OVER	FULL - EXTEN	Shoulder and Ankle Alignment	Horizontal Plane	media 0.07 dp 0.04	media 0.03 dp 0.08	media -0.01 dp 0.06	p=0.001	p= 0.10 dp 0.04	media 0.05 dp 0.04	media 0.01 dp 0.05	p<0.001	media 0.13 dp 0.04	media 0.07 dp 0.04	media 0.04 dp 0.06	p<0.001			
			Vertical Plane	media -1.38 dp 0.05	media -1.39 dp 0.05	media -1.37 dp 0.06	p=0.891	media -1.39 dp 0.05	media -1.40 dp 0.05	media -1.38 dp 0.05	p=0.647	media -1.38 dp 0.05	media -1.40 dp 0.05	media -1.39 dp 0.05	p=0.927			
		Hip and Knee Alignment	Horizontal Plane	media -0.05 dp 0.03	media -0.06 dp 0.03	media -0.04 dp 0.03	p=0.119	media -0.05 dp 0.03	media -0.06 dp 0.03	media -0.03 dp 0.02	p=0.022	media -0.06 dp 0.03	media -0.06 dp 0.02	media -0.03 dp 0.03	p=0.044			
			Vertical Plane	media 0.38 dp 0.03	media 0.39 dp 0.03	media 0.40 dp 0.03	p=0.120	media 0.38 dp 0.02	media 0.39 dp 0.02	media 0.39 dp 0.02	p=0.230	media 0.39 dp 0.02	media 0.39 dp 0.02	media 0.40 dp 0.05	p=0.715			
	CATCH - 1st	Shoulder and Ankle Alignment	Horizontal Plane	media -0.06 dp 0.03	media -0.04 dp 0.04	media -0.01 dp 0.05	p=0.006	media -0.03 dp 0.03	media -0.03 dp 0.04	media 0.01 dp 0.04	p=0.016	media -0.01 dp 0.04	media -0.02 dp 0.03	media 0.00 dp 0.04	p=0.724			
			Vertical Plane	media -1.21 dp 0.05	media -1.24 dp 0.05	media -1.31 dp 0.06	p<0.001	media -1.20 dp 0.05	media -1.22 dp 0.06	media -1.31 dp 0.06	p=0.001	media -1.17 dp 0.05	media -1.21 dp 0.05	media -1.28 dp 0.08	p=0.001			
		Hip and Knee Alignment	Horizontal Plane	media -0.19 dp 0.04	media -0.19 dp 0.05	media -0.09 dp 0.10	p<0.001	media -0.20 dp 0.04	media -0.20 dp 0.05	media -0.09 dp 0.10	p<0.001	media -0.23 dp 0.03	media -0.20 dp 0.03	media -0.13 dp 0.10	p=0.001			
			Vertical Plane	media 0.32 dp 0.03	media 0.33 dp 0.03	media 0.38 dp 0.06	p<0.001	media 0.30 dp 0.02	media 0.32 dp 0.02	media 0.37 dp 0.05	p=0.001	media 0.28 dp 0.02	media 0.32 dp 0.02	media 0.36 dp 0.05	p<0.001			
RECOVERY	CATCH - 2nd	Shoulder and Ankle Alignment	Horizontal Plane	media -0.06 dp 0.04	media -0.05 dp 0.03	media -0.02 dp 0.05	p=0.040	media -0.05 dp 0.03	media -0.04 dp 0.04	media -0.01 dp 0.04	p=0.007	media -0.04 dp 0.03	media -0.04 dp 0.03	media -0.02 dp 0.05	p=0.118			
			Vertical Plane	media -1.19 dp 0.07	media -1.15 dp 0.10	media -1.28 dp 0.10	p=0.001	media -1.17 dp 0.06	media -1.17 dp 0.07	media -1.27 dp 0.13	p=0.010	media -1.11 dp 0.07	media -1.16 dp 0.06	media -1.25 dp 0.11	p=0.001			
		Hip and Knee Alignment	Horizontal Plane	media -0.20 dp 0.06	media -0.24 dp 0.06	media -0.08 dp 0.12	p<0.001	media -0.21 dp 0.05	media -0.23 dp 0.12	media -0.10 dp 0.12	p<0.001	media -0.24 dp 0.05	media -0.23 dp 0.05	media -0.11 dp 0.12	p<0.001			
			Vertical Plane	media 0.30 dp 0.04	media 0.28 dp 0.06	media 0.37 dp 0.06	p<0.001	media 0.29 dp 0.03	media 0.30 dp 0.03	media 0.36 dp 0.08	p=0.008	media 0.26 dp 0.04	media 0.30 dp 0.03	media 0.35 dp 0.07	p<0.001			
	FIN - POS	Shoulder and Ankle Alignment	Horizontal Plane	media -0.03 dp 0.03	media -0.02 dp 0.04	media -0.01 dp 0.05	p=0.560	media -0.03 dp 0.03	media -0.02 dp 0.03	media 0.00 dp 0.05	p=0.010	media -0.02 dp 0.03	media -0.02 dp 0.04	media -0.02 dp 0.03	p=0.913			
			Vertical Plane	media -1.35 dp 0.05	media -1.36 dp 0.05	media -1.35 dp 0.06	p=0.723	media -1.34 dp 0.05	media -1.37 dp 0.05	media -1.36 dp 0.08	p=0.489	media -1.34 dp 0.05	media -1.37 dp 0.05	media -1.36 dp 0.06	p=0.378			
		Hip and Knee Alignment	Horizontal Plane	media 0.01 dp 0.03	media 0.01 dp 0.03	media 0.00 dp 0.04	p=0.329	media 0.00 dp 0.02	media 0.02 dp 0.03	media 0.01 dp 0.02	p=0.326	media -0.01 dp 0.03	media 0.01 dp 0.03	media 0.01 dp 0.05	p=0.076			
			Vertical Plane	media 0.39 dp 0.03	media 0.40 dp 0.02	media 0.40 dp 0.05	p=0.184	media 0.39 dp 0.02	media 0.40 dp 0.02	media 0.40 dp 0.02	p=0.211	media 0.39 dp 0.02	media 0.40 dp 0.02	media 0.40 dp 0.05	p=0.709			

The hand drawn figures below aim at being a visual representation of some important distances presented in table 4.

Figure 5 – Contact - Full Extension - Catch: A – EXP; B – ME; C – NOXP; D – NOXP.



i) Dashed lines are fixed, having for reference the Experienced Group. This will serve as a comparison point, to better understand the body positions of the two other groups in relation to this; ii) Between Contact and Full Extension, there is a bigger leg potential to extend explosively and it is possible to see a more pronounced travel of the shoulders to a posterior position, which translates into a more explosive movement. This happens when

comparing the EXP to ME and NOXP; iii) The ME group stands in a middle ground in the point above. They present more jumping potential than the NOXP, but less than the EXP. iv) Legs travel less distance from Contact to Full Extension and to Catch, in the NOXP, while comparing to the other two groups.

Graphs: Barbell trajectories and Velocities

It is important to state that some limitations have to be considered when analysing the trajectories and velocities graphs:

- The barbell paths graphs shows the averages of the movements of each group, in each lift and considers the vertical and horizontal plane simultaneously, which is not good to compare some details in between lifts, despite being the average displacement of each lift;
- The objective data collected by the system show the exact position, but further explanations to what was presented above can be obtained through these graphs analysis. Besides, the graphs are a good visual guide to translate some numbers into visual references;
- The velocities graphs show the average velocities obtained in each lift by each group;
- They represent the velocities and they are normalised for the average of each lift;
- This means that it is incorrect to compare directly the timings of each lift. The percentage of time of each line corresponds to the timeframe of that lift alone, despite the scale presented (for reference only).

Barbell trajectories - Graph

- The following figure (figure 6) contains three graphs with averages of barbell movement of the NOXP, ME and EXP group, for the 40%, 60% and 80% lifts;
- X-axis represents anteroposterior displacement (% height) and the Y-axis represents vertical displacement (% height);
- Each color represents an experience level: NOXP (blue), ME (red) and EXP (green);
- Graph displays effectively the displacement because the position values have been normalised;

- Although the bar was not truly at a zero position (it was about 10 cm high due to the wooden platform, as shown in figure 2, regarding the barbell layout), the values here refer to the variation from that initial position, therefore, displacement.
- Trajectories Graph General Analysis
- Despite having differences in the curves, “S” shaped lines seem to appear as the weight increases;
- NOXP seems to have the highest catches and two out of three lifts display what’s seems to be a barbell crash;
- NOXP also displays biggest horizontal displacements in Catch;
- Still for the NOXP, three different lines are displayed, and the higher their weight, the more “S” shape the lines are, despite the inconsistency;
- ME always presents an initial rearward movement, but it seems inconsistent with the lines presented, as well as a barbell crash in the first lift;
- ME presents a medium size horizontal displacement in the Catch (considering the two other groups);
- EXP provide a consistency throughout all lifts, with the main differences being in the 40% and 80% lift. The first shows their greatest horizontal displacement after Contact and the closest to body line is the 80% one.

Trajectories Graph Analysis - 40% Lift

- Trajectory is closer to the vertical line in NOXP;
- ME and EXP display an “S” shaped line, with a more pronounced rearward initial movement in the EXP;
- Catch was performed fast, maintaining the upwards movement in the EXP;
- Barbell trajectories indicate a barbell crash on the shoulders in the ME and NOXP;
- Biggest horizontal displacement in Catch happened in the NOXP, followed by the ME;
- Small barbell displacement in the EXP;
- Highest Catch performed by NOXP;
- Most forward barbell displacement was found the EXP.

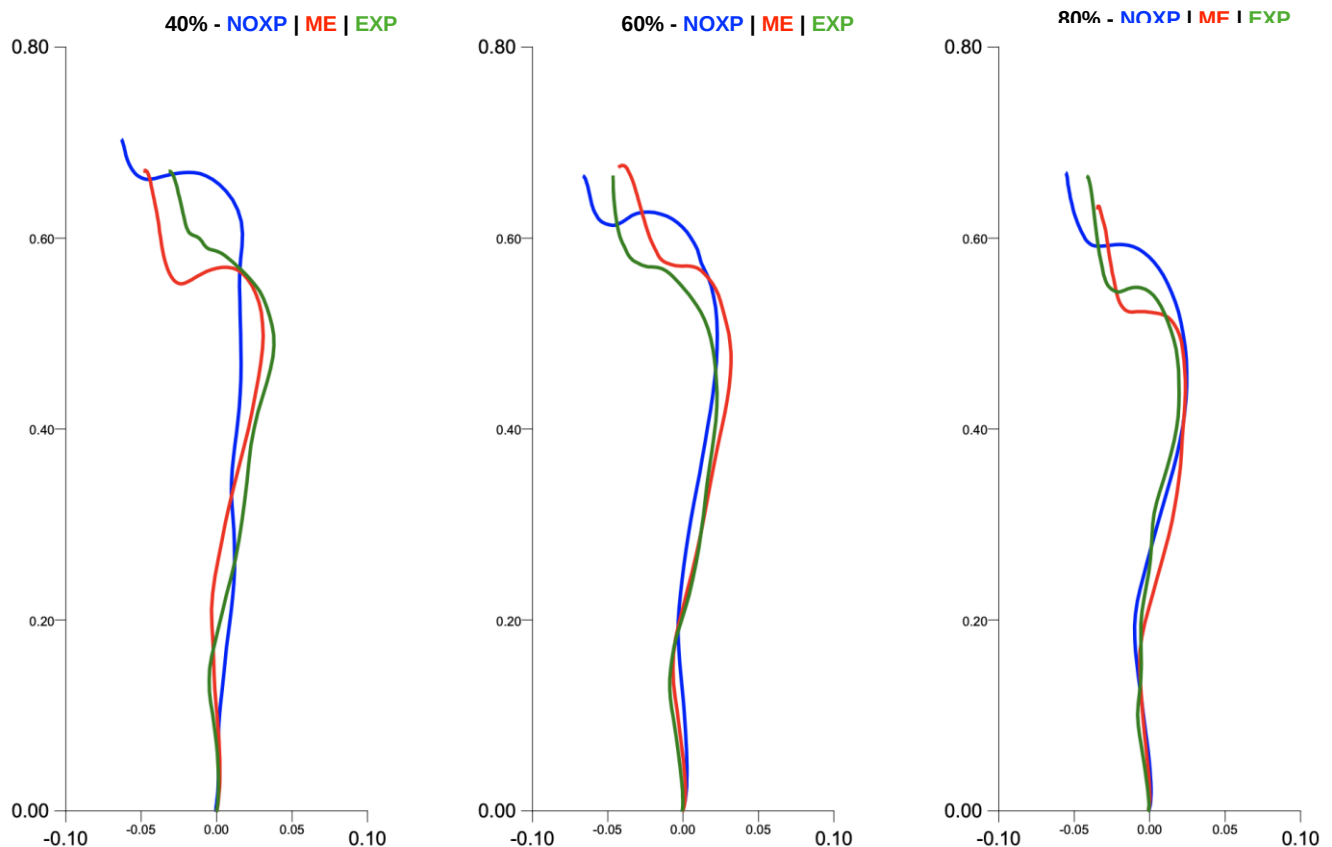
Trajectories Graph Analysis - 60% Lift

- “S” shaped line is present in the three expertise levels;
- EXP displays the most pronounced rearward initial movement, a fast Catch, almost maintaining the barbell upwards movement, and with the smallest horizontal displacement;
- Barbell seems to have crashed on the NOXP shoulders, in average;
- Fast catch also shown in ME group, with the barbell horizontal displacement being bigger than the EXP, but smaller than the NOXP.

Trajectories Graph Analysis - 80% Lift

- “S” shaped line is present in the three expertise levels;
- EXP displays the most pronounced rearward initial movement, a fast Catch, almost maintaining the barbell upwards movement, and with the smallest horizontal displacement;
- EXP displays the closest to body trajectory, under the higher load task;
- Highest Catch belongs to the NOXP, in average;
- Fast catch also shown in ME group, with the barbell horizontal displacement being bigger than the EXP, but smaller than the NOXP;
- Despite the ME being here visually presented as the lowest height Catch, it can be confirmed in the alignments table (table 4) that it is not. It belongs to the EXP. These virtual representations, as stated above, can present some biases, due to the horizontal and vertical averages.

Figure 6 - Trajectories - Experience Dependent —40%, 60% and 80%: No-experience (NOXP) in blue, Medium-experienced (ME) in red and Experienced (EXP) in green.



Vertical acceleration - Graph

- The following figure (figure 7) contains three graphs with the averages of barbell vertical velocities, of the NOXP, ME, and EXP groups, for the 40%, 60% and 80% lifts;
- Barbell speed is measured since the lift until final position;
- Time is normalised;
- X-axis represents time expressed as % of task time;
- Y-axis is the vertical speed of the bar;
- Each color represents an experience level: NOXP (blue), ME (red) and EXP (green).

Trajectories Graph General Analysis

- EXP always presents a Second Pull than faster the First Pull, and they always present the lowest speed averages;
- ME are inconsistent with the speed attained in relation to the loads;

- Inconsistencies are also found in ME in the Catch Phase. The same happens with the NOXP;
- In what regards higher loads, it is not possible to establish a pattern to between speed and catches in the two latter groups, and there are some abnormal speed peaks in the NOXP and ME.

Velocities Graph Analysis - 40% Lift

- First barbell acceleration displays similar lines;
- There is a deceleration right before Knee Cross in the NOXP, that might indicate contact with the knees;
- The only group which presents a second velocity peak higher than the first one, is the EXP. The NOXP has a second pull slower than the first (in speed), and the ME display a line that suggests a barbell being rushed off the floor, which is a common mistake (Everett, 2014);
- Fastest Catch is seen in the EXP, without a zero-velocity line cross;
- Slowest Catch belongs to the NOXP;
- The Catch phase done with a higher momentum was the ME one, which is consistent with the trajectory graph;
- Fastest average speed belongs to the ME, followed by the NOXP, and then the EXP.

Velocities Graph Analysis - 60% Lift

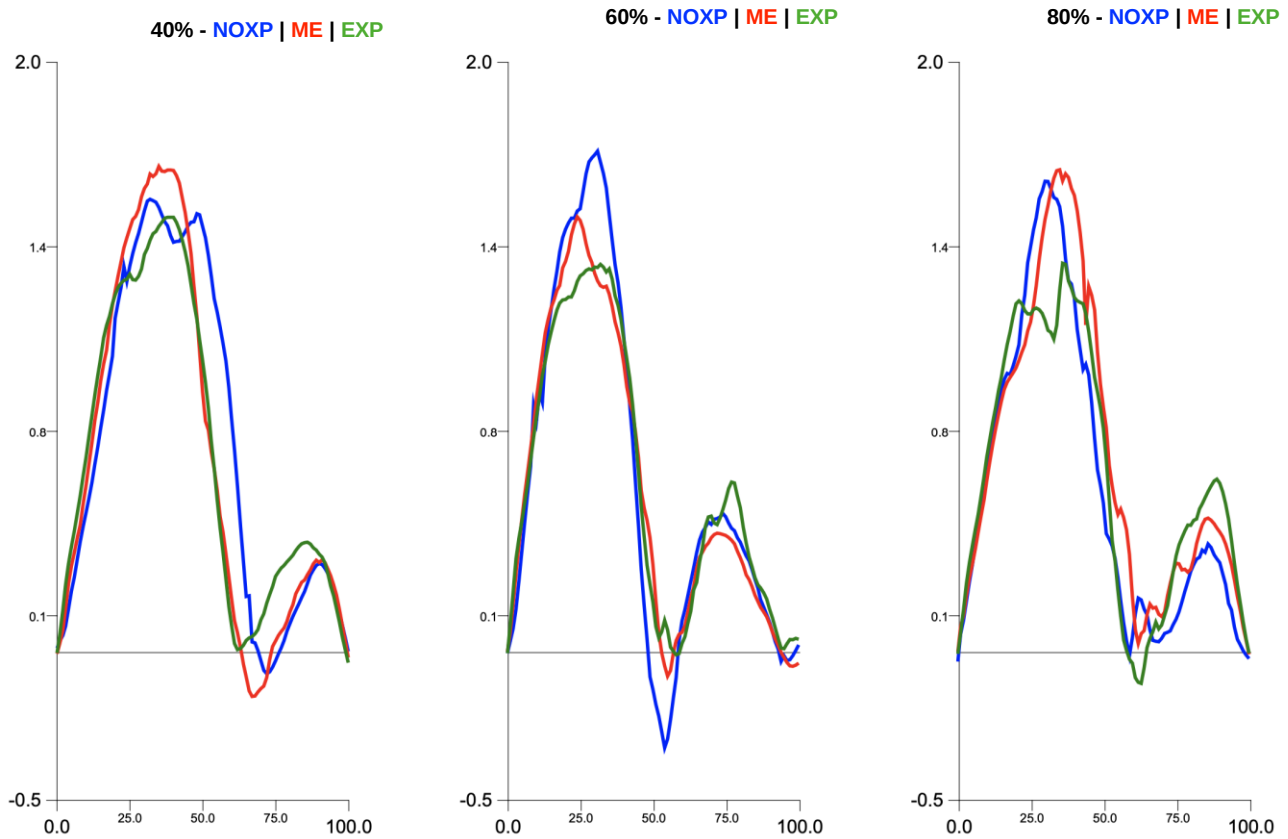
- There seems to be again some sort of interruption in the First Pull for the NOXP, probably caused by contact to the knees before Knee Cross. Despite this, the Second Pull achieves a higher speed than the First Pull;
- There is an apparent barbell rush off from the floor on the ME. Together with this, there is another small peak after this rushed first acceleration, which suggests a contact with a harsh momentary deceleration, and then the extension. This may be caused by the extreme arm pull, noticed in table 4;
- Second Pull is slightly faster (in speed) than the First Pull in the EXP;
- Barbell was caught with the biggest downwards acceleration of the three lifts, in the NOXP;
- ME displays a short Catch, with low momentum;

- EXP displays the fastest Catch, with very little momentum;
- The oscillations presented close to the Catch of the EXP seem to be related to the elasticity of the barbell;
- Fastest average speed belongs to the NOXP, followed by the ME, and then the EXP.

Velocities Graph Analysis - 80% Lift

- Clearly faster Second Pull than First Pull in the EXP;
- Barbell seems to have been rushed off the floor in the ME;
- Very short second velocity peak suggests the same deceleration present in the previous lift, in the ME;
- Fast Catch, with the highest loads, caught with relatively low momentum, in the EXP;
- Lowest average speed belongs to the EXP and the highest to the ME;
- ME do not display a barbell drop, even though this was the 80% lift.

Figure 7 - Velocities - Experience Dependent. A – 40%, B – 60% and C – 80%: No-experience (NOXP) in blue, Medium-experienced (ME) in red and Experienced (EXP) in green.



Figures 8 and 9 below display hand-written notes, to better enlighten the above statements regarding barbell trajectories and velocities.

Figures are divided in the NOXP and ME separately, to better compare the barbell movement in each percentage of the 1RM lifted. Individual graphs for the EXP will be presented in the next section.

Figure 8 - Non-Experienced - Trajectory and Velocity: No-experience (NOXP), Medium-experienced (ME) and Experienced (EXP). 40% in blue, 60% in red and 80% in green.

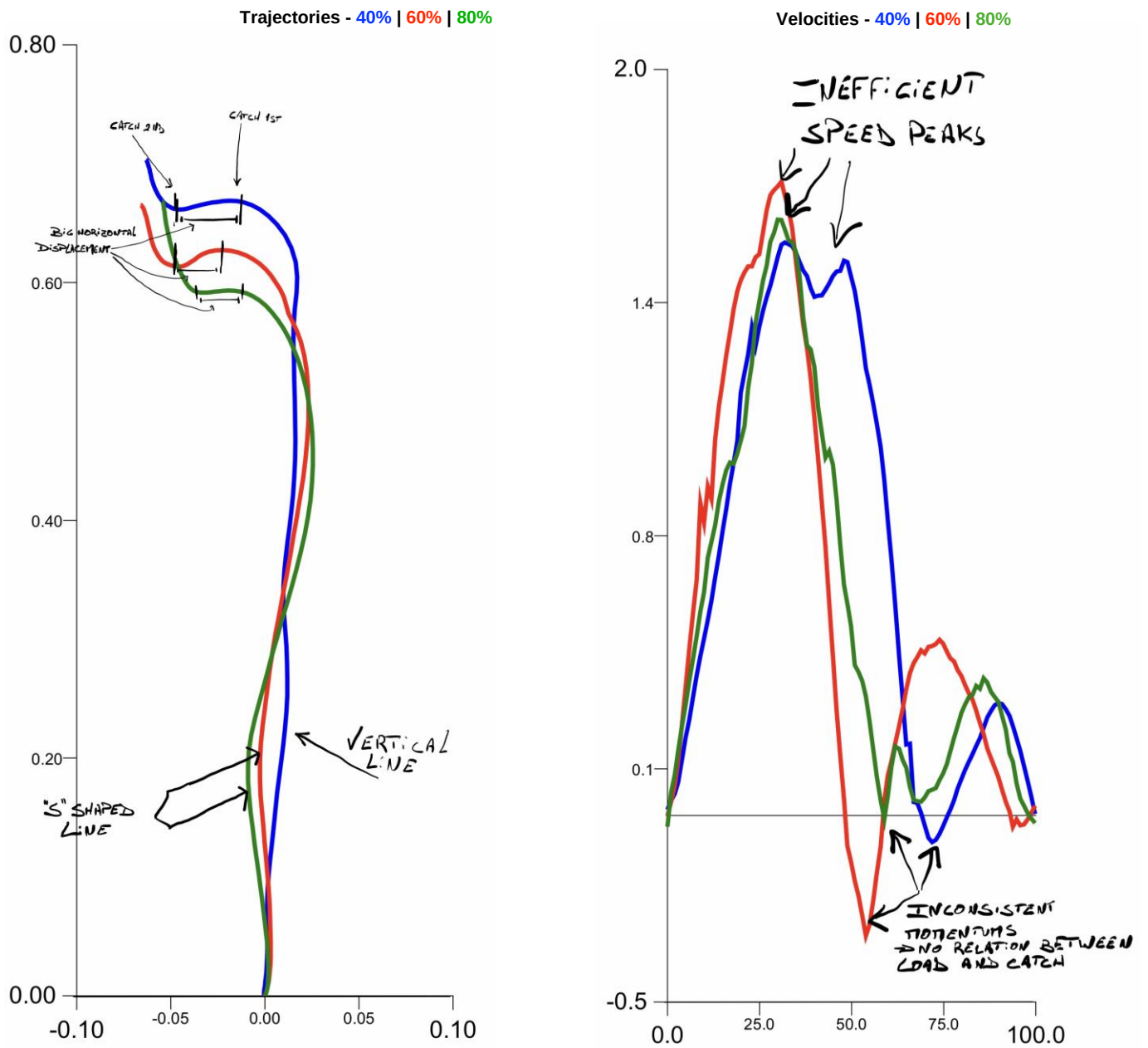
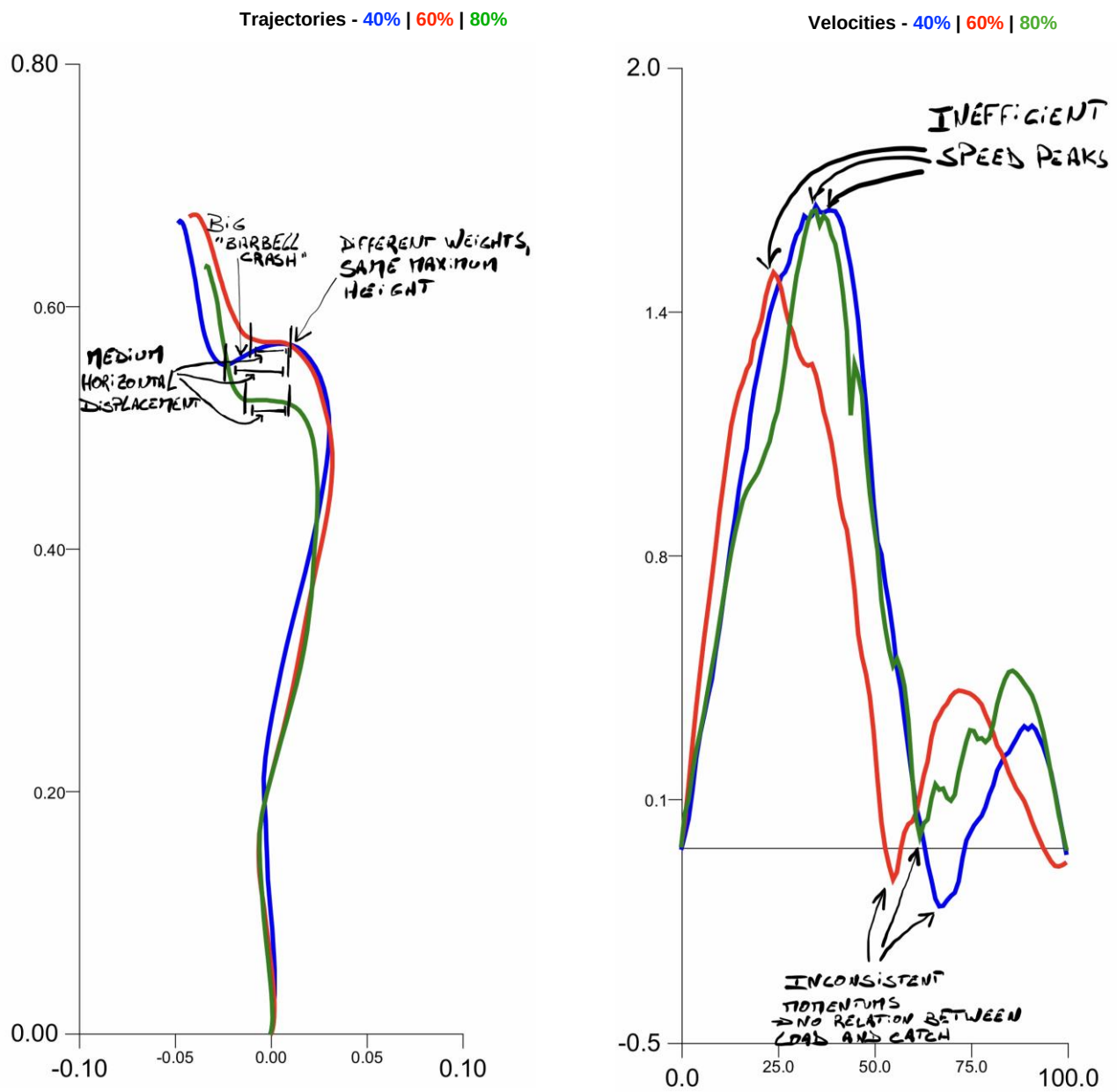


Figure 9 - Medium Experienced - Trajectory and Velocity: No-experience (NOXP), Medium-experienced (ME) and Experienced (EXP).
40% in blue, 60% in red and 80% in green.



TECHNIQUE ANALYSIS OF THE EXPERIENCED GROUP

In order to establish a pattern to compare to, it will be verified if the Experienced group present in this study has the proficiency levels needed to be considered an advanced group. For this purpose, several performance points, as well as key points of high experience and technique demonstrated above, will be compared, to verify if the theory relates to the data collected in this group. In this section, the Experienced group information alone will be analysed, the two other groups being not considered.

Technique proficiency, according to what should be expected to encounter in an Experienced group, will be assessed following what is presented in the Hypothesis topics.

Barbell trajectories - Graph

- The following figure (figure 10 - Trajectories) contains a graph with the averages of barbell movement for the Experienced group, for the 40%, 60% and 80% lifts;
- Handwritten notes were taken in the figure to simplify readings;
- Graph displays effectively the displacement, as the position values have been normalised;
- Although the bar was not truly at a zero position (it was about 10 cm high due to the wooden platform, as shown in figure 2, regarding the barbell layout), the values here refer to the variation from that initial position, therefore, displacement;
- X-axis represents anteroposterior displacement (% height) and the Y-axis represents vertical displacement (% height);
- Each color represents a load level: 40% lift (blue), 60% lift (red), 80% lift (green).

Barbell Trajectory - Analysis

- There is a first initial reward movement in the three lifts which increases as the load increases. The 40% lift displays a slight delay in this reward movement. As stated by Bartonietz and Klaus (1996), it is necessary to balance the system centre of mass (athlete plus barbell) as soon as the barbell leaves the ground and navigate it around the body. In this case (40%), due to the low weight present, this necessity is considerably reduced, which may explain this small delay;
- The barbell displays a consistent “S” shaped line, in the three lifts

- As the weight increases, there is more proximity of the barbell in relation to the body
- Specially in the heavier lift, there is a clear pull with the arms toward the legs in the second pull, right before contact. This reinforces Bartonietz and Klaus (1996) theory regarding the need of balancing the centre mass and navigation around the body, which is here shown to be more efficient as the necessity increases;
- In the turnover there is a good elbow pulling “up and back” because the barbell has a small degree positive displacement, which shows a controlled ricochet effect, redirecting the barbell to where it is supposed to go;
- Alongside with the previous point, the catch first and second, have a very short horizontal displacement, which again shows that the elbows were pulled nicely up and back. The exception for this is, again, on the 40% lift. In this lift, the contact threw the barbell away from the body of the athlete; however, the catch phase was very fast. There was not a descent register. This means that the barbell was caught on its ways up, showing explosiveness in the pulling phases, and speed in the catch. Again, this more pronounced forward displacement should be explained by the low weight, which is more prone to be affected by small errors;
- The catch phase is very fast in the three lifts, as stated above regarding the 40%. In the 60% lift, the barbell does not display an explicit downwards movement. This means that with a medium load, the catch is fast enough not to allow gravity to accelerate the barbell down, catching the barbell with low momentum;
- The 80% lift, as expected, displays a small descent line. Nevertheless, it is a small degree descent, which shows again that the catch is fast, even if the load is high.

Vertical Acceleration - Graph

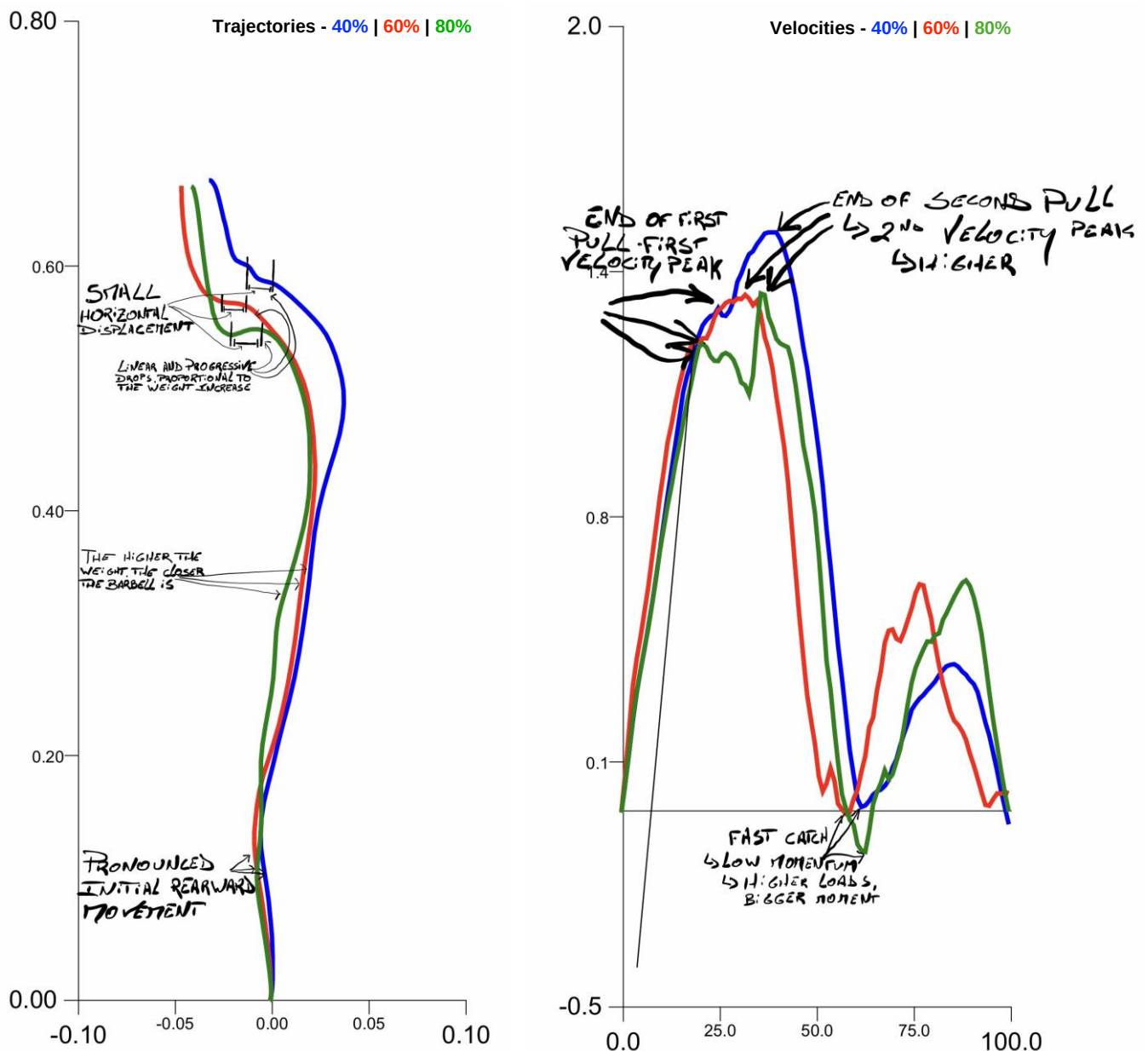
- The following figure (figure 10 - velocities) contains the averages of barbell vertical acceleration of the experienced group, from the lift until final position;
- Barbell speed is measured since the lift until final position;
- Time is normalised;
- Handwritten notes were taken in the figure to simplify readings;
- X-axis represents time expressed as % of task time. Y-axis is the vertical speed of the bar;
- Each color represents a load level: 40% lift (blue), 60% lift (red), 80% lift (green).

Vertical Acceleration - Analysis

- In every lift, it is shown a first speed increase, followed by a decrease, and only then it is obtained the peak velocity. This refers to the First Pull and Second Pull, respectively, and it is as it should be in a proficient technique;
- This speed drop is more pronounced in the 80% lift, as expected, due to the higher load in this transition phase, or “non-weighted phase”. Then, a more pronounced acceleration is presented, since the line is more vertical than the one shown in the First Pull. In other words, more speed is gained in less time;
- The previous statement explains the difference between the more force production phase and the more power production phase - First Pull and Second Pull;
- The three catches happens in a short time frame, proportionally to each lift;
- After the Second Pull and throughout Turnover, it is possible to see a barbell momentum increase, as the weight increases. In the 40% lift, experienced athletes are so fast in the Catch phase, that the barbell’s average movement displays a continuous ascent movement - barbell does not cross zero value. In the 60% lift, the downwards movement caused by gravity starts to appear, even if it is only significant in the 80% lift. This means that the technique proficiency is high enough to display proportional body movements adjustments according to the weight increase.

As stated above, the graphs shown serve an illustration purpose, providing a somewhat visual guide for the data collected in the system. Nevertheless, in the following topic, true values will be analysed to provide detailed information.

Figure 10 - Experienced Group - Barbell Trajectory and Velocity - 40% in blue, 60% in red and 80% in green.



Body Alignments

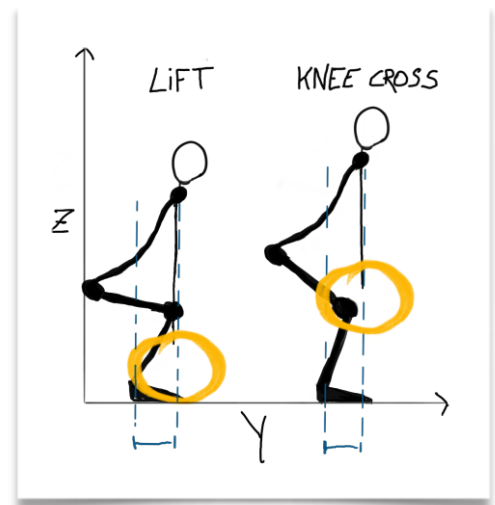
As explained in the methods topic, distances of shoulders in relation to the ankles, and hips in relation to the knees were registered, both in vertical and horizontal planes. These distances, taken at specific moments, will help to analyse the technique proficiency.

To transfer easily numbers to a visual representation, some manual drawings were done. These drawings are not in any exact scale, but have in consideration relations such as shoulders in front or behind the ankles and how high, or the same relation for the hips and knees.

Body Alignments - Analysis

- The start positions in the 3 lifts are virtually the same, which suggests a good body awareness, and consistent positioning;
- Horizontal displacement between shoulders and ankles shifted only 1cm, from the 1st pull until the start of the second pull (at knee cross), in the lifts of 40% and 60%, and 3cm in the 80% lift, which shows an excellent maintenance of shoulder alignment, even in the presence of a more tasking load (figure 11 illustrates what the absence of this displacement should look like);
- Contact occurs with shoulders in an anterior position in relation with the ankles, while hips are still in an incomplete extension, which means that the body is ready for a powerful full extension;
- Elbows flexion occurs between contact and full extension;
- Full extension alignments display a proficient movement explosiveness, because shoulders shift from an anterior position in contact, to a more posterior position than the ankles, and hips to a posterior position in relation to the knees, in a diagonal line with a posterior tilt. These two positions (contact and full extension) are represented in figure 1, numbers 3 and 4, drawn in consideration of the movement of the Experienced group;
- Barbell maximum velocity is observed just 1% before the full extension is reached, related to the full movement, going in line with the results presented by Lee, as stated in the bibliography revision section. This means that the mechanics of the movement was explored taking advantage of all phases of the movement, while extending the body;
- Catch phase is dynamically correct, shifting shoulders from the posterior position related to the ankles in the catch 1st, to a catch 2nd, with shoulders, hip and knees forming a solid triangle, to a stable catch and recovery. Figure 12 represents the dynamics of the Experienced group, of a transition from a fully extended and tensioned position to a relaxed state going through Catch First, until the solid Catch Second is achieved. Visual representations are also shown. Red represents distances of shoulders and ankles and hips and knees in the vertical plane, which

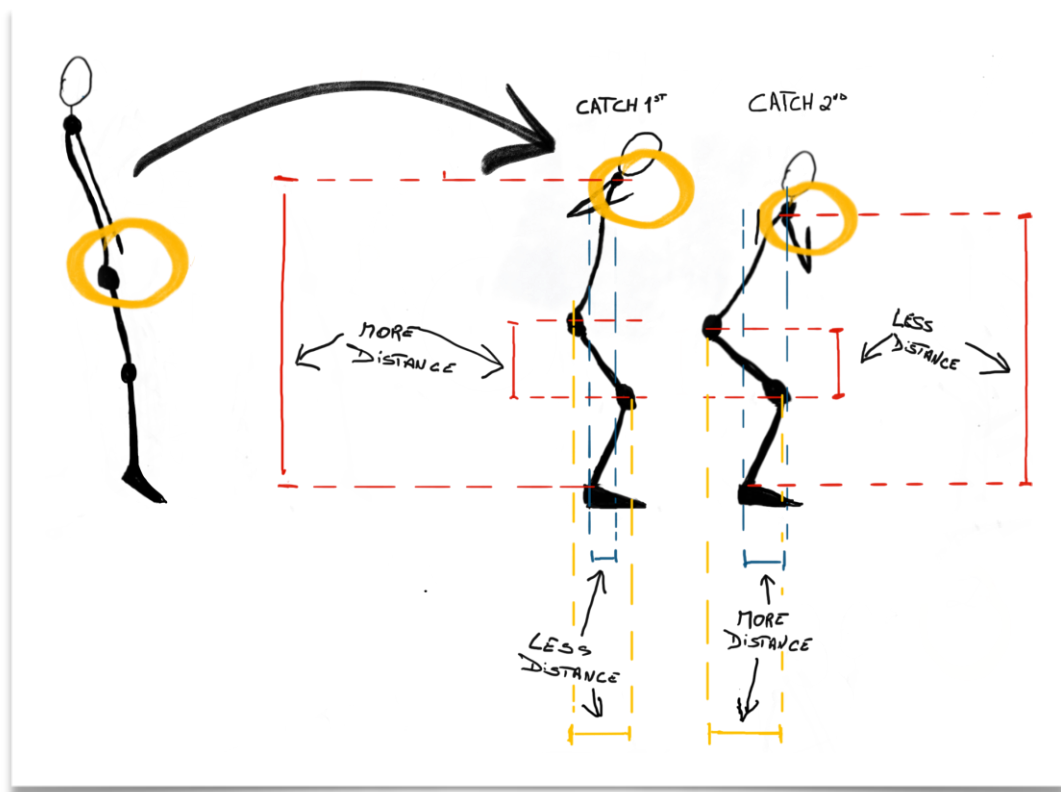
Figure 11 - Lift to knee cross



will represent mainly the height of the catch. Blue represents horizontal distance between shoulders and ankles, and yellow the horizontal distance between hips and knees. These latter also have impact on the height of the catch, but in a lesser degree. Nevertheless, they are very important to show if the Catch is proficient. For example, if the Catch Second had the hip in an anterior position in relation to the knees, this would be an obvious example of a bad Catch position and technique.

With the above information, data suggests that the experienced group has a solid proficient level of technique that could serve as a good comparison point to the medium and no experience group.

Figure 12 - Dynamics of going from Full Extension to Catch First and Catch Second - Experienced Group



DISCUSSION

In the present topic, every phase and event data will be thoroughly analysed. Step by step, technical considerations will be enlightened and then the proficiencies of the different groups will be compared, having established the Experienced Group above as the baseline.

Phases will be numbered as established above. Events occurring inside each phase, will be numbered accordingly, and each event will be dissected, culminating in a summary of each phase as a whole. In phases where events are absent, there will not be such a final full movement summary.

1. First Pull Phase

This phase shares similarities with the traditional deadlift. A coach can prepare an athlete to learn this phase even if he is not yet learning how to perform a Power Clean.

When looking at the barbell trajectory, it is shown that when the weight is higher (60% and 80%), there is an “S” shaped line for every expertise level, which does not confirm Verkhoshansky's (1998) claims that the appearance of the “S” shaped line corresponds to increased expertise. This “S” shaped line seems to appear not only by technique proficiency, but also to navigate the barbell around the body and control the centre of mass, as pointed out by Bartonietz and Klaus (1996). For the latter purpose, the most important factor seems to be the weight.

Having in mind that the “S” shaped line occurs in all of the three lifts of ME and EXP, and in the 60% and 80% of the NOXP, data suggests that the First Pull is more easily understood and it may be where the least differences are found. It is obvious that in the teaching process, the proper body alignments should be taken into account, as well as the purpose of the First Pull, which is to give a first acceleration to the barbell, while maintaining the proper angles (Everett, 2014; Torokhtiy, 2022). That being said, a vast majority of the people who usually train with external load to improve strength, should be familiar with the deadlift. This may be an explanation for why the duration, timing and body alignments have more in common in the three groups of expertise than in any other phase. Despite these facts, further analysis will enlighten more details.

1.1. Lift and Knee Cross

From a statistical point of view, there are not significant differences to register in body alignments between the three groups, with just two exceptions. Differences found indicate just lack of consistency in the setup of the unexperienced group. Either the shoulders or the hips start in a different position. No pattern can be established to this group when starting a lift.

What cannot be assessed through two static points of observation like these, is precisely the dynamics of the movement. For that reason, while comparing the average barbell trajectories of the lifts, the EXP seems to have a more consistent and controlled path than the NOXP. As for the ME, in the trajectory of the First Pull alone, differences do not seem to be significant.

The ME is consistently the group which spends less time in this phase and the NOXP is the most incoherent. The common ground to these two groups is that, in two out of three lifts, the First Pull takes more time and the Second Pull less time. The reasons why this happens seem to be quite different, though, and a further analysis of this, has to be continued in the following event where the arm pull is also assessed.

First Pull - Full Movement

Although this is arguably the lowest technical demanding phase, it is obvious that the First Pull Phase needs to be taught, and there are numerous reasons why it still needs to be reinforced, such as gaining a full understanding of its first acceleration purpose, acquiring true knowledge of correct alignments for body awareness, and others. However, even for someone who is completely new to it, it is not the major concern while teaching the Power Clean technique. Still, one of the biggest emphasis that should be given towards the goals of this phase is that it should not be rushed. The arms should be relaxed, and it is mainly to create a stable first barbell acceleration, while maintaining the proper body angles. The pull should be made by “taking the knees out of the way”, to create the initial rearward movement and correct muscle engagement (Charniga, 2020; Everett, 2014)

As the skill level improves, different errors seem to appear. Interestingly, knowing in advance what to expect and with a proper approach, it might be possible to reduce the appearance of some of them.

Despite the lower skill need of this phase, a coach or athlete always should consider that the evolution from a novice to someone who has a medium level of experience will proceed from not understanding the full technique concept, into trying to lift heavier loads. In other words, going through having no experience to having some, seems to result, generally, in a tendency to rush phases, events, and alignments, compromising the following by not fully respecting purposes of the latter.

This indicates that progressions should be prepared in a way that the tempos and alignments are emphasised throughout the learning curve.

2. Second Pull Phase

After the first acceleration promoted by the First Pull, the already-in-motion barbell, has to surpass the height of the knees right after their first maximum extension. It follows the non-teachable re-bend or non-weighted phase, in which the legs accumulate power to explosively extend and jump (Everett, 2014; Torokhtiy, 2022). All of this has to be accompanied by correct body angles that are able to promote explosiveness. A good example would be the universal athletic position, that weightlifting mimics, for a powerful vertical extension. According to Enoka (1979) and Torokhtiy (2022), this explosive phase, or Second Pull, is characterised by the register of the peak velocity, preceded by a very short in time deceleration, which is shown in the velocities graphs of the Experienced group. This supports the data that show a shorter in time Second Pull, compared to the First Pull.

2.1. Contact

In regards to Contact event, it should be noted that every subject of the EXP had presented a real and effective barbell-to-thigh contact, but 2 out of 15 of the ME and 7 out of 15 of the NOEXP did not. This means that 13% of the ME and almost 50% of the NOEXP, did not have the ability or knowledge (theoretical or practical) to perform an important part of the technique.

The fact that the Experienced group display a slightly more vertical torso position and a slightly more bent leg position, indicates that their bodies alignments have a bigger potential to finish the pull explosively. Despite not representing statistical differences, it is the combination of several measurements that, together, allocates the body in a different

position. In this case, it is similar to the universal athletic position. The number 2 of the figure 5, 6 and 7 illustrates better what the sum of these small differences means. In the end, the translation is: the less the experience, the poorer the power readiness position.

Alongside with the above, the small velocity peaks observed in the 60% and 80% lift suggest that in the ME, the barbell was set up in Contact to the thighs by the early arm pull, followed by a momentary halt, and only then the movement continued.

This data suggest that an important part of the teaching process should be given to the Contact event. This is a twofold assessment and should happen from novices until medium experienced athletes. One refers to the physical contact itself. The other to the correct body position that should occur upon contact.

As a side note, given the relatively low percentage of the ME that do not have enough proficiency to perform this event, data also suggest that with a proper approach, it might be possible to sweep away the mistake of not being able to apply contact, in a relatively short amount of time. In other words, it should be possible to easily reduce or eliminate this mistake within a group with medium experience.

2.2. Elbow Flexion

One of the common technical mistakes to point out in weightlifting is an early pull with the arms, or elbow flexion (Everett, 2014). This was also observed in the two less experienced groups of athletes in a very high degree, to a point where some lifts had an almost simultaneous arm bend along with the beginning of the movement. Still, in average, both ME and NOXP, start the arm bend even before the Knee Cross event. This arm pull should happen after the Contact event and closely timed with the barbell maximum velocity.

According to data, as the load gets higher, the lack of technique proficiency seems to lead to an extreme early arm pull. In other words, higher loads for less experienced athletes, seem to translate into the necessity of pulling with the arms sooner than they should.

On the EXP, there is an increase in time from Contact to Elbow Flexion, as the weight increases, which can be explained by a deeper re-bend of the knees due to the higher loads. This seems to force the Contact to happen with a more bent leg position. This is confirmed by the alignments table (table 4) and translates into more time since Contact

until the greatest barbell acceleration through the powerful leg extension. Alongside, it also explains why the acceleration of the Second Pull in the highest load, is the most pronounced of the 3 lifts: more time to explosively extend legs and jump. This is also a possible explanation for why the velocity curves in the ME and NOXP do not translate into a faster second velocity peak: there is less potential of the legs to extend, due to a shorter flexion and a forward leant torso (hips raised faster than torso).

Theoretically, the timing of the Elbow Flexion in relation to the Contact and Barbell Maximum Velocity, should be closer to the latter than the Contact. This means that, even in EXP, the timing of the arm pull is a performance point that seems to be mandatory to further enhance and train, because even though their arm pulling is in between the two correct events, its timing is closer to the wrong one. For this purpose, it might be important to consider exercises that promote the feeling and understanding of “relaxed arms” very close to the full extension is reached.

2.3. Barbell Maximum Velocity

This event is the culmination of all the previous steps and what happened until this event occurs. Everything that happened before is, simply put, the preparation for this event. This is a key point. To be successful, one should be capable of accelerating the maximum weight possible, properly. For that, a lot has to happen in a very methodical way.

In a statistic point a view, and despite the timings presented being different in this event, except for the 80% lift, the body alignments are quite similar in the 3 lifts, for the 3 groups. The maximum velocity of the barbell occurs with 3 out of 4 body alignments in a similar position but, when analysing what happened before, different mechanisms were used to achieve it. The exception of the alignments is at the shoulders position in relation to the ankles. As experience level gets lower, shoulders position tends to have a more anterior position at the point of maximum velocity. Experienced ones, have the shoulders already travelling back, and in a posterior position, in relation to the ankles. This is mainly explained by the explosiveness of the Second Pull when it is done correctly, technically speaking. In a “textbook” technique, while analysing Contact and Barbell Maximum Velocity, it is possible to see an anterior shoulder position in the first, followed by a very explosive leg extension that, together with the load, leads to a fast shift from anterior to posterior shoulder position in relation to the shoulders. This is what happens in the present study with the EXP.

Despite the facts presented above, due to lower loadings in terms of mass, mechanically, the NOXP do not need to apply as much power as the EXP to apply as much power as the EXP, so a smaller degree shoulders backward lean might be expected as well.

In sum, as experience decreases, the tendency goes from shoulders in a posterior position (vertical to ME), into an anterior position (in the NOXP).

Again, one event alone does not provide sufficient information. A well presented technique should follow the correct steps: using First Pull to initially accelerate a rested barbell, then explosively going through a Second Pull with the arms relaxed, into a jump and finally using the arm pull to redirect the ricochet effect to where the barbell is supposed to go up.

For example, the exaggerated early arm pull presented both in ME and NOXP is a common error, in which the barbell is pulled towards the contact point, or to a comfortable zone to the user, starting in the middle of the First Pull. In turn, when looking at lighter weights, which can easily be more controlled by simply pulling with the arms, the barbell will reach certain areas with an inconvenient timing, thus failing the correct timings to fully take advantage of the explosive potential of the Second Pull. Having said that, when looking at what happens in the NOXP, this early pull is combined with a load that can easily be more controlled by the arms alone. Because of this, they fulfilled a considerable portion of the task earlier than it was supposed to happen. The barbell was pulled towards the area of contact and, from there on, when the most explosive phase should reach its full potential, the body is not properly aligned to the most powerful extension it can get.

This explains a more anterior shoulder position in relation to the ankles, which is maintained throughout the full movement, in the three lifts of the NOXP, and reinforces the previously mentioned slower Second Pull. They always take more time to reach their maximum speed than any other group, regarding the time of the full movement.

In the ME, things are slightly different. There is a mix of the two other groups. On the one hand, the early arm pull also leads to a more forward lean of the torso in the contact, despite being in a lesser degree than the NOXP. On the other hand, there is a greater amount of work shifting the torso to a more posterior position than the ankles, caused by a more aggressive jump, despite the lesser degree shown in the EXP, which shows a more explosive second pull than in the NOXP.

Again, in figure 5 – A, B and C, the drawing will help to enlighten the alignments present in table 4; in this case, specifically in what concerns the Contact, where it can be visually more understandable the explosiveness potential of each group.

This event is something impossible to see with a naked eye and without very expensive equipment. Therefore, it is not applicable to real life purposes and “in the field”. Nevertheless, it is still the culmination of several steps that precede it, and it is a very fast passage immediately before the Full Extension occurs, which is easier to spot. What should be reinforced until this point is the correct assessment of the previous steps; it is also vital to ensure that the barbell maximum velocity “background” has a consistent foundation.

2.4. Full Extension

As a side note, this event can be considered as the consequence of the previous steps combined together to achieve maximum barbell speed. The Full Extension happens afterwards, because the event before caused it.

After the Contact, as previously mentioned, the legs and torso should explosively and simultaneously extend into a jump. Somewhere in between Contact and Full Extension, but closer to the latter, the highest acceleration that the barbell will receive should be accommodated. This event goes in line with what happened in the previous one. The body has to fully extend into a jump while holding a barbell, and ideally the maximum velocity should occur very closely to the latter. This implicitly means that more acceleration potential was harnessed. In other words, the Full Extension moment is a final consequence of the maximum barbell acceleration.

Having said this, and considering shoulders position of the NOXP and the EXP, between Contact and Full Extension, as well as the time needed to go through these two phases, what the data show us is that the Experienced ones have a more powerful extension. For example, in the 80% lift, the horizontal shift of the shoulders in relation to the ankles is 29cm for the EXP e 22cm for the NOXP, with the same distance in the vertical plane. They have covered more distance with a significantly higher load, in less time.

Another very important factor is that distances are being measured horizontally and vertically. If we consider the body alignments of EXP and NOXP, the hips of the first group are 6cm behind the knees and 39cm above. Looking just at this data, this would mean that

the legs would be less extended than in the NOXP, in which the hips are 3cm behind the knees and 40cm above. That is not the case because the shoulders are 18cm behind the ankles in the EXP and 4cm in the NOXP, which means that the position is more diagonal, causing a bias to this observation. Both present the same height of shoulders related to the ankles. Considering that there is no height difference between these two groups, this is only possible if the EXP presents a more pronounced full body extension than the NOXP, which again shows a more powerful action.

Another fact that seems important to look at is that NOXP only display a posterior shoulder position in this event, and not in every lift. The other two groups display it already in the Bar Maximum Velocity.

Another important fact is that there is more shoulder displacement from the Maximum Velocity to Full Extension in the NOXP, less in the ME and even less in the EXP. This information suggests that the NOXP has less awareness of when they should start to go under the barbell, and the more the experience, the sooner one starts preparing the drop for the Catch, which goes in line once again with Verkhoshansky's (1998) and Enoka (1979) statements, regarding the fast drop and that the maximum speeds should occur slightly before the Full Extension occurs.

The Full Extension is one of most transferrable capacities that weightlifting can provide to other sports. It is the consequence of a strong vertical jump that starts from a static position. The ability to jump vertically and explosively should always lead, as a consequence, to a full extension, or triple extension. In this case, under a load that promotes a good balance between strength and speed, in the Power Clean.

To those who lack the ability to fully extend properly and then go for a receiving position, it might be a good approach to create conditions to learn and understand the mechanics of a jump into a solid receiving position and then apply progressive load.

Second Pull Phase - Full Movement

As to the barbell movement going up, this is the most technical phase of the Power Clean. What data seems to suggest is that, with different technique levels, different mechanisms are used to achieve the same goal.

Similarly to the First Pull, a coach or athlete should expect different ways to address similar problems. Two different erroneous methods are seen in a slower Second Pull, when compared to the First Pull: for the NOXP, the complexity of the Second Pull seems to dictate an overreaching with the arms power, in an attempt to succeed a lift in a slow and un-explosive moment. For the Medium Experienced group, what seems to be the case is that they try to lift the weight starting off with an immediate full acceleration, using as much muscle power as possible. This leads to the earlier arm pull of the three groups.

As the technique experience improves, athletes start by not comprehending how to accelerate the barbell, proceeding to a phase where they accelerate it wrongly, by over-speeding the movement and mixing events, causing timing faults. Both indicate lack of a better understanding on how the movement should develop, step by step. In the case of the NOXP, there is no clear view of what should happens. The ME clearly know the events but fail the timings.

3. Turnover

This phase will be shortly summarised, because it has a direct connection with the following. It implicates going from powerful full body contraction to a very fast drop and relaxation state, going under the barbell for the Catch phase. The Turnover is measured from the point where the Full Extension is registered until the barbell ceases to go up, and its velocity is zero. At this point, it is only when the weight lifted is the heaviest, that it is possible to statistically find differences. When the load is manageable, all groups seem to have the ability to move at the same rates under the barbell. This seems to happen for two reasons, both caused by the existence of less weight: 1) less need to go under the barbell, as the catch can be done mainly in an upwards movement; 2) no need to extend in a highly explosive way, which means that, going from full extension to a relaxed state, is an easier task.

As to the Turnover duration, as the expertise decreases, the differences increase. Being this phase one of the highest performance points, this fact alone provides evidence that one of the mechanical aspects to consider while teaching novices, is the drop movement in which the proficiency decline is more obvious while under a more strenuous load. This does not mean that it should be taught under high loads. It means that it is easier to understand the magnitude of the error under a higher load. However, mechanically, it would make sense to fully understand and develop under more controllable loads, as part

of the teaching/ learning curve. If analysed without the barbell as a bias, the Turnover phase is nothing more than the preparation for a strong landing from a vertical jump. This connects directly to the Catch Second.

It has to be considered that when the technique is high enough, it is likely to happen a take off with both feet off the ground, or at least a near absence of load on the feet in the switch of Second Pull to the Transition, with a consequent landing. This landing should be aggressive and full footed.

If one considers this portion of the movement in relation to Full Extension until Catch, being aggressive and flat footed while landing should be one of the key points to consider while teaching.

4. Catch

Even though the Catch is divided into Catch First and Catch Second, as a phase it will be analysed as one. It is in the timeframe between the Catch First and Catch Second, as well as in the body alignments of the latter, that the most valuable data can be collected. It is also where most errors are observed.

This phase is always faster in the EXP in terms of the duration, considering the full movement. For a better understanding, there should be pointed out that the slowest Catch of the EXP group is faster than the fastest Catch of any of the other groups.

It is important to note that there is a significant difference concerning loads in absolute values in between groups (see table 1). This means that, even under the highest loads registered, the EXP are faster moving under the barbell, which again goes in line with Verkhoshansky's (1998) theses regarding the transition from a fully contracted and extended position under load to a relaxed state going under the barbell, to a proficient and solid position for a successful Catch. Interestingly, in this group, the higher the load, the faster the Catch. The EXP move faster as the weight increases. This is true for the EXP, but not for the NOXP, where there is not the possibility to establish a pattern. In the ME, the Catch speed increases from the 40% to the 60% lift, but not to the 80%, where it remains virtually the same, considering the full movement time.

When it comes to time taken in Catch Phase, interestingly, the experienced group is not the fastest one while going through Full Extension to Catch First. It is even the slowest, if

the three groups are compared in the 40% and 60% lift. Things change when it comes to Full Extension to Catch Second, where EXP is always the fastest of the three groups. What this means is that there are few differences in time going from Full Extension until the moment where the barbell ceases to go up. Catch differences are exactly in the point where the barbell starts to go down; that is where the Experienced Group really show a big difference, thus catching the barbell with less momentum as possible, as referred by Nagao (2019).

When combining the above with the body alignments, the EXP have a faster catch and they travel more distance. When going through Full Extension to Catch Second, shoulders go down 28cm, and travel 17cm forward. These distances are 23cm in height and 11cm horizontally to the ME, and to the NOXP 14cm and 6cm. It means that the EXP move faster, under more load, while travelling considerably more distance.

Another very important note refers to the 5 subjects of the Non-Experienced group that displayed a critical error while catching the barbell. The number 3 of figure 8 visually enlightens what an anterior position of the hips to knees and what a posterior position of the shoulders to ankles in combination mean. Considering that this previous error was not observed in the ME and the EXP, it is to be expected to find it mainly in athletes with no experience in Olympic Weightlifting.

A good Catch is similar to landing structurally solid from a vertical jump. In this particular case, the jump is small or nearly absent, but it is under load and stressful conditions. The proper approach while teaching a correct technique might be through mechanising jumps and landing, from and to the Universal Athletic Position. This might mimic what needs to be done, other than landing with hips more forwards than the knees and shoulders behind the ankles. This is far more important to the group without experience, but the training of such ability should always be present

Elbows rotation also has a big role in this phase. When arm pull is done by rounding the movement, the barbell is set away from the body and the horizontal displacement in the Catch gets bigger and another error is observed: a barbell crash on the shoulders (Everett, 2014). This is seen in the NOXP, reduced in the ME and improved significantly in the EXP.

The horizontal displacement related to the elbow rotation movement, should be mechanised with low loads or free movements, and progressively increase loadings, while

verifying if the barbell starts crashing in the shoulders and/ or deviate from the athlete's torso.

The Catch phase is where most differences were observed. Time-wise and alignments-wise.

Some errors tend to disappear along with experience increase, but others just reduce its magnitude. Catch phase seem to be one of those cases. The less height difference between Catch First and Second, the better (Nagao et al., 2019).

Data presented seem to suggest that drills to increase speed, correct body alignments and barbell displacement to the Catch are fundamental to the NOXP, but speed drills and barbell displacement drills should remain addressed to a ME group, which have learnt promptly the mechanics, but still lack consistency and speed. This does not mean that the Experienced group can no longer benefit from these drills. This only means that they already show more proficiency at this point. Nevertheless, as seen before, this is one the main concerns to be addressed.

5. Recovery

Simply put, this phase refers to the act of extending the legs after the barbell is resting on the shoulders, after the Catch is done.

The NOXP presents faster recoveries. This is not necessarily better. When crossing data, two possibilities to explain this arise:

1. Higher catches: meaning that they have less distance to travel up;
2. Lower loads: catching and mechanically oppose a downwards moving mass, back to a positive vertical acceleration is more likely to be slower when the load is higher.

To better explain the above, where the ME is slower than the EXP, in average, in the Recovery phase, despite having lighter loads to lift, some important notes have to be considered: the EXP have both technique and strength levels well developed, or at least they have spent more time in training these two determinants. This means that, at this point, their execution performance is closer to their physical limits than the one of the NOXP. More training is related to more weight lifted, and more weight means more barbell elasticity. This can be one of the causes for this. Since a Power Clean is a movement that has to be stopped while not going to a full squat, more barbell elasticity means that the

athlete might need a bigger amount of time stabilising the load and preventing unbalances, which is likely to present vertical oscillations, and then rise. This will translate into a prolonged Recovery Phase. By opposition, the NOXP is more limited to the technique than to the ME, which translates into lower loads, less oscillations and easier task when recovering.

Final ME and NOXP Comparison

As expected, differences between groups were observed. To summarise the data obtained, it follows a comparison between the technical errors measured and observed in the ME and in the NOXP.

Rushing the barbell off the floor is a very common error in novices (Everett, 2014). While looking at the NOXP alone and despite this group tendency to be faster in the First Pull than in the Second Pull, rushing does not seem to be the case here. Despite this, there seems to be a tendency to rise the hips faster than the shoulders, which is another common error (Everett, 2014). It lacks the explosiveness that characterises a rushed off barbell, right from the start. What data analysis suggests is that although the full movement is not entirely clear and understood, the First Pull might be faster in this group for two reasons: 1) it is a simple task, with a relatively low ability requirement, very similar to a traditionally well known exercise - the deadlift; 2) it has a lower weight, when compared to the other two groups.

By contrast with the ME, who have already some technique proficiency and understanding, and are able to successfully lift considerably higher loads than the NOXP.

As to the medium-experienced one, it becomes more evident that there is the tendency to rush off the floor, as an attempt to wrongfully gain as much speed as possible, fast and right from the beginning. This is one of the main concerns to be taken into account. This might explain as well the reason why it is in the ME that the elbows start to flex sooner. One possible reason for these errors to happen is a deficit in understanding that, although speed is very important and it will help to lift more weight, you need to master the full movement comprehension and be aware that each phase has its purpose and all of them should be overcome in order to take the most out of each.

As to the early arm pull, which is a technique error especially when it surpasses 30° to 40° angles and continue to flex, before the contact occurs (Charniga, 2020), and despite the fact that two out of three lifts of the ME and the NOXP display this error, it seems to happen by different reasons. Rushing the barbell off the floor usually can lead to a hip rise faster than the shoulders (Everett, 2014), and it can enhance the need of pulling with the arms, to compensate the forward leant torso. In the ME, this is more evident in the heavier lift, where it can be seen a 4cm forward shoulder shift, since the Lift to Knee Cross, and where the elbow flexion starts sooner. A fast hip rise indicates that something is wrong and there are possible reasons for that: 1) lack of comprehension of the purposes and clear distinction between First and Second Pull; 2) strength imbalances; 3) an attempt to be excessively fast, not having proper mechanics (Everett, 2014).

The ME is the group, of the three, which uses less time in the First Pull, regarding the full movement. This, along with a greater tendency to pull early with the arms, were the main factors that led to the consideration that the ME rushes the barbell off the floor and the NOXP do not. The NOXP have significantly less weight to lift, and despite being faster in the First than in the Second, they are still slower than the ME in the First.

In summary, similar mistakes happen in these two groups, but they happen, apparently, for different reasons: a fast hip rise and an early arm pull might occur in the NOXP mainly due to lack of understanding and mechanisation of the technique. In the ME, there seems to be a barbell rush off the floor, that leads to the fast hip rise and to the most precocious arm pull of them all, in an attempt to wrongfully gain as much speed as possible at the beginning of the movement.

On the Second Pull, the NOXP, in percentage, spend more time in each lift in this phase, if compared to the other groups. To someone who is not familiar with such a complex technique, lack of proficiency is expected to occur, slowing the movement down. It might not be clear to everybody that, when taking a barbell off the ground and placing it on the shoulders, most of the work has to be done with the legs. Having that said, it appears that this group are trying to do most of the work by using their arms. This is only possible due to the lighter loads used, that are controllable enough to enable the chance of using the power of the arms in the attempt to lift the barbell successfully, which is probably the main reason why this group has the lowest 1RM average. The full movement is neither understood, nor properly mechanised, and that seems to lead to the biggest amount time

spent in this phase. This suggests that pulling soon with the arms is caused by different reasons from the ones that affect the ME.

One of the main differences of the arm pull in the Non-Experienced group, regarding the ME, is that almost 50% of them do not make physical contact of the barbell with the thigh. This translates into a purely mechanical and low technical lift, with low leverage caused by the absence of all the steps that should precede in a highly proficient technique.

The fact that an important part of the work is done with the arms and not with the legs also induces a more forward leant torso and more extended legs at the moment when the movement should go up rapidly. This translates into a poorly explosive Second Pull, that has to be compensated by the torso movement to vertical position.

When looking at the ME, and despite not being as slow as the NOXP, this group still presents a slower Second Pull, when comparing to the First Pull. Having in mind that the barbell was rushed off the floor and the arms started the pull too early, with the consequences mentioned above, when it comes to the Second Pull, there is a poor angles maintenance, leading to a weaker power position. When the hips rise fast, the torso is delayed. Now, the same early arm pull seems to lead to the positioning the barbell on the correct contact place but in a wrong timing, followed by a momentary stop and then a jump, mainly led through a torso movement and with less leg extension to drive up. This can dramatically decrease the movement potential and creates conditions to other errors such as a catch with a forward jump (Everett, 2014).

The ME does not seem to lack explosiveness, but rather lacks control of how to use it properly. To sustain this affirmation, data also shows that this group has the shortest sum of the First and Second Pull in the three lifts, which means that they move the load fast. They just do not move it in the best way possible. Alongside with this, a fast shift from posterior position to anterior from Contact to Full Extension is seen, which again sustains the presence of a somehow explosive movement, even though it is done with an incorrect pattern.

After the Second Pull is done, it follows the phase where the most differences were found: the Catch.

NOXP is the one that expends more time in this phase. One third of the members of this group presents the biggest error in the Catch, which is translated in the position presented

in the number 3 of figure 11 - Shoulders are behind the ankles and hips are more anterior than the knees. This group is also the one where the most pronounced horizontal displacement of the barbell was registered. This is usually caused by a poor elbow rotation or even by a fast hip rise with a forward leant torso (Everett, 2014). These occurrences can be noticed, either simultaneously or separately, in some members of this group. Again, the lack of comprehension and mechanisation of the movement may be the most important factor causing the differences found in this phase.

In what concerns the full movement, if the three groups are compared, the ME are faster than the NOXP, but slower than the EXP, in the Catch. Some proficiency is there, they know what to do, but the correct timing and transition from a very explosive to relaxed state is still not sharp enough, which indicates lack of expertise (Verkhoshansky, 1988). Alongside, horizontal barbell displacement is shorter than in the NOXP, but it still presents a significant magnitude. This statement corroborates the latter, in which some proficiency is present, but there is still some work to be done, technically speaking.

Power Clean, as well as any other Olympic weightlifting technique, is technically demanding. The learning process is supposed to be reasonably long and one expects errors to occur in the athletes' learning curve, before they fully master it. This is why a coach should firstly understand if and when it makes sense to apply this technique as part of his training method, and to whom.

Simply put, a Power Clean is nothing more than a vertical jump, along with a barbell that starts on the ground. At the end of the jump, the barbell should be resting on the shoulders. One of the first things an athlete should learn is how to jump and land for a Power Clean.

This said, it may be possible to save a great amount of time in error correcting, if a theoretical part of the technique is given prior to practice. Having the athletes to fully understand the mechanics, body alignments and proper timings could potentially help to reduce several common errors, or at least, reduce their impact. A great example for this is the fact that Non-Experienced athletes usually do not rush the barbell off the ground. This is mainly because they still do not comprehend the technique and are not aware they need speed. On the other hand, when one starts to understand that speed will help to set the bar higher, they usually starts rushing things up, jeopardising the movement and the

technique. This happens because they may understand that speed helps, but do not know when and how to apply it properly.

Considering that the benefits derived from the Power Clean must take into account a proper technique, the outcomes of an insufficiently proficient technique, may simply be significantly reduced. This means that it might make sense to include Power Clean in training programming, only after a certain level of proficiency is met.

As experience levels increase, different details can be observed and may impact the outcomes of using Power Clean as part of a training program.

The experienced group is the only one in which the duration of the First Pull takes more time than the Second, and the same happens with alignments, trajectory lines and velocities. This suggests not only that this group is constant even when under light and controllable loads, but it also reinforces what the available literature refers concerning a slower First Pull and a faster Second. In turn, it also reinforces that the First Pull is where the most force is produced, and the Second bears the most power production. This happens due to the fact that the weight is resting on the ground and it has to be accelerated firstly, thus being slower. When the limit of how much an athlete can lift is more physical than technical, and the work intensity is high, this is exactly what mechanically will happen: slower in the beginning, explosive to the jump and land.

This first acceleration will occur until it is possible to explode up, in the Second Pull, where the weight is already moving, the most power is generated and maximum speed is attained. What happens in the Medium experienced and Non-experienced groups is that the movement is incoherent. They usually have a Second Pull slower in time than the first. In some cases even in speed.

Data seems to suggest that new athletes, with weaker strength base and with low weightlifting technical capabilities, may firstly develop a solid strength base while learning a good weightlifting technical base, without a physical enhancement purpose.

That way, while still taking advantage of the mechanical patterns and respective sports transfers in the learning process, the athlete should be physically more prepared to absorb the benefits that weightlifting brings to the sport specific needs when the proper time comes to introduce higher intensity to the techniques mentioned above.

Considering the differences in the explosiveness achieved during Second Pull and Catch, unexperienced athletes may not be able to fully capitalize on the force and power production phases of the movement. They seem to be slow in the beginning, and even slower since Contact until Full Extension, despite being able to reach similar maximum speeds. This suggests that they simply apply more force when absolutely needed, just to be able to succeed the lift, despite the previous errors, instead of using mechanical and technical advantages to attain the speed needed to lift with success. This indicates lack of proficiency and not lack of power. It also suggests that unexperienced athletes may not be able to fully benefit from the power clean for performance enhancements, until they get at least medium experience. Further investigation should be done for a better understanding of this.

On the other hand, Medium Experienced are not apparently able to take as much advantage as expected in the First Pull (less force is likely to be produced). Being able to be this fast probably means that one important reason why they are unable to lift higher loads may be the lack of technique expertise. This means that they would be able to lift a heavier load, if their technique was better. Here is what often happens in many cases when athletes use Power Clean as a training method: if athletes with the same physical capacities, but one highly experienced and the other medium experienced, are working with 80% range of their 1RM, the first should be able to successfully lift a heavier load. This means that the First Pull will have different force enhancements outcomes and the Second Pull should have different explosiveness training outcomes, for both athletes.

CONCLUSION

As expected, different expertise levels present different outcomes.

Surprisingly, some technical mistakes seem to be learned during the process of developing a proper technique, which means that they did not exist, or existed in a smaller degree. Therefore, there should be possible for the coach and athlete to avoid them, or reduce their magnitude, by using a proper approach focusing on what is supposed to happen.

This investigation does not intend to establish any kind of teaching protocol, but rather suggest aspects both the coach and the athlete should consider to avoid avoidable mistakes. It specifically addresses common faults and provides tools to help both of them to make the most of their best capabilities and control the outcomes.

Although findings confirmed most of the hypothesis, some were not confirmed and others were only partially confirmed, depending on the expertise level. It is also important to note that even though some hypothesis were verified, in different expertise levels, different reasons apply:

- Verkhoshansky's (1988) statements about the "S" shaped lines being present only in more experienced athletes, seems to be true exclusively in lighter loads. This indicates that in the absence of the need to balance the centre of mass, the unexperienced athlete chooses the shortest route - a straight line. This translates into a partial confirmation, that novices that lack experience tend to have a straight line trajectory, but when the load gets higher - at least 60% of their 1RM - the "S" shape appears. This means that it is the load that controls that need in the NOXP. It is not their choice. The ME and the EXP display an "S" shaped line in every load;
- The two velocity peaks, the second peak being higher than the first one seems to occur only when looking at an Experienced athlete. This suggests that a deeper comprehension of the technique and proper mechanisation can take some time to be absorbed. In this particular case, experienced athletes have at least two years of contact with Olympic weightlifting;
- Besides, knowing beforehand what errors are expected to occur throughout the learning curve, new approaches should be considered in an attempt to reduce the amount of time needed to achieve the technique full potential;

While comparing EXP with ME and NOXP the following was verified:

- There was a more constant start position in the EXP than in the two other groups, especially in the NOXP; however, only a very small percentage of differences in the alignments, were found, all related to the hip height;
- At the moment when the barbell passes the knee line, very few differences were registered and with low significance. Despite this, data indicate that the dynamic portion was apparently very different in between the Lift and Knee Cross.
- Barbell contact with mid thighs does occur with shoulders covering the barbell, but not only in the EXP. this was verified In every group . As in the previous point, it should be taken into account that data suggest that all the previous steps taken to reach to that position were significantly different between groups, and that some errors start to become more evident as novices become medium experienced athletes;
- When considering the moment at which the elbows start to flex, the timing is very close to the ideal in the EXP, and similarly far from it in the ME and the NOXP, despite being due to different reasons. In the ME it is more associated with an excessive attempt to accelerate the movement, whilst in the NOXP it results from a lack in the understanding of it;
- Body extension is directly proportional to the expertise. If the experience level is higher, a more pronounced full body extension is expected, as a consequence of a proper use of each phase and adequate movement explosiveness;
- The Catch is where the main differences are found and; therefore, emphasis should be put on the understanding and mechanisation of that portion of the movement. This can result either from an excessive horizontal barbell displacement caused by a fast hip rise, a round movement of the arms in the pull, lack of timing, or even from a combination of all of them. Until an athlete does not have the proper proficiency to Catch, different variants of the Power Clean should be applied, such as pulls and high pulls, which can mimic several movement benefits, but without the catch phase;

Findings suggest that the aspects that follow should be considered when teaching the Power Clean:

- It is important to understand the trajectories, but contrary to Verkhoshansky's

- Lack of understanding about timings, durations and alignments. Too slow in NOXP and too fast in ME, and lack of full moment comprehension, as well as the purposes of each individual phase and event;
- Early arm pull gets worse from NOXP to ME;
- Contact is either inexistent in NOXP, and when done, it is done generally in an incorrect way, both in NOXP and ME;
- NOXP lack explosiveness and usually do not jump to lift, or in other words, the extension and barbell acceleration is insufficient, which leads to an insufficient propulsion;
- Inefficiency in elbows rotation is greater in NOXP, but still exists in ME. Mechanisation of movement and fluidity is to consider;
- Catch phase is the most uncomprehended in the NOXP. A jump and a landing with an external object should be mechanised, so as to make it clear how a solid Catch should feel and look.

As expected, EXP seems to show a lesser degree in technique variation, despite the increase in load. As the expertise increases, some errors that did not exist in the beginning, start to appear or be more evident. This suggests that there should be further investigation on what kind of progressions and teaching processes may be more efficient to reduce the learning curve timeframe, knowing beforehand the errors that are supposed to occur.

Having that said, it should be considered as well that, until technique proficiency is not high enough, the benefits of using Power Clean as part of a training program, can be reduced to an uncertain level. A guideline, suggested by Greg Everett, indicates that an athlete's Power Clean should be roughly 60-70% of their deadlift (Everett, 2014). This is supposed to happen in experienced individuals well familiarised with the technique. It is also important to note that the Deadlift and Power Clean engages different muscle groups and require distinct movement patterns, especially in the Second Pull. The Deadlift is a low skill and mostly posterior chain exercise, whereas the Power Clean has an explosive, full-body phase, that is technically demanding (Hori et al., 2005).

While there does not seem to be a solid consensus about the ratio of 1RM Deadlift and a 1RM Power Clean, the general guideline of 60-70% might be used as a starting point. This means that, it is possible that the outcomes of the use of this technique will be different for athletes who cannot comply with this general guideline and those who can.

RECOMMENDATIONS FOR FUTURE RESEARCH

Further investigation interesting, to better understand to what extent an athlete can take advantage of this technique as part of his training method, depending in its expertise.

Further investigation should be done to conclude if the outcomes of performance enhancement are different, depending on the expertise levels. Besides, further investigation is suggested to compare real differences in the movement pattern of each group in between loads, to establish if there is a more user friendly load, that simultaneously can provide the desired results in performance boost.

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