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COMPARISON BETWEEN OLYMPIC WEIGHTLIFTING EXERCISES AND DERIVATIVES FOR FATIGUE IMPACT QUANTIFICATION

Dissertação

Mestrado em Treino Desportivo

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General Index

Table Index

Figure Index

Abbreviations List

- IMTP – Isometric Mid-thigh Pull
- SPT – Snatch Pull Test
- kg – Kilogram
- m – Meters
- RM-Repetition Maximum
- OW- Olympic Weightlifting
- PBF-Percentage body fat
- w-Watts
- cm-Centimeters
- m/s-Meters per second
- ROM-Range of motion
- FFM-Fat free mass
- C&J-Clean & Jerk
- ES-Effect Size

Resumo

Título: Comparação entre movimentos de Halterofilismo e seus derivados na quantificação do impacto de fadiga

A gestão da carga de treino é um aspeto de extrema importância na gestão de fadiga e indução de adaptações em quase todas as modalidades, sendo que no halterofilismo são conhecidas algumas das variáveis de carga, nomeadamente a intensidade e volume. No entanto a tipologia do exercício permanece uma incógnita em termos concretos porque o empirismo nos diz que alguns exercícios induzem maior fadiga que outros, contudo não é conhecido em concreto a razão dessa quantificação. Dessa forma, este trabalho quantificou a fadiga induzida por vários tipos de exercícios de halterofilismo através de um desenho experimental, onde foi induzida fadiga em indivíduos adultos atletas de halterofilismo com experiencia mínima de 2 anos, através da execução de um conjunto de 10 dos exercícios mais utilizados em halterofilismo, em que foi equalizada a intensidade e volume entre eles (4 séries de 3 repetições), após os quais foi efetuado um teste de *Snatch Pull* e avaliada a variação da velocidade média e máxima, amplitude de movimento e potência média como medida de fadiga, pré e pós execução do protocolo de cada exercício, através do transdutor linear marca Vitruve (Vitruve encoder; Madrid, Spain).
Participaram nove mulheres e doze homens (respetivamente, idade, 29,67±5,74 anos e 28,17±5,06 anos; estatura, 158,78±6,70 cm e 174,50±6,07 cm; massa corporal, 60,84±7,34 kg e 79,46±5,32 kg; %massa gorda, 17,76±7,63 % e 16,98±5,14 %). Relativamente a amostra total, foram encontradas diferenças significativas na amplitude de movimento dos exercícios de *Snatch Pull, Snatch e Back Squat* (respetivamente, p<0,001 e *Effect Size* (ES)=0,986; p=0,003 e ES=0,731; p=0,021 e ES=0,547) e na amplitude de movimento de *Clean and Jerk (C&J)* (p=0,015 e ES=0,582), na potência média, foram encontradas diferenças significativas no *Power Snatch, Snatch, Snatch Pull e Back Squat e no C&J* (respetivamente, p=0,043 e ES=0,472; p=0,048 e ES=0,460; p=0,003 e ES=0,729; p=0,009 e ES=0,636; p=0,037 e ES=0,488), na velocidade máxima foram encontradas diferenças significativas no *Power Snatch, Snatch, Snatch Pull e Back Squat* (respetivamente, p=0,008 e ES=0,638; p<0,001 e ES=0,998; p<0,001 e ES=0,906 ; p<0,001 e ES=0,906), na velocidade média, foram encontradas diferenças significativas no *Snatch Pull* e no *Back Squat* (respetivamente, p=0,030 e ES=0,509; p=0,003 e ES=0,727), quando analisados os géneros separadamente, no grupo feminino, encontramos diferenças significativas na amplitude de movimento do *Snatch*, *Snatch Pull* e *Back Squat* (respetivamente, p=0,006 e ES=1,218; p=0,001 e ES=1,776; p=0,002 e ES=1,474), na variável potência média, foram

encontradas diferenças significativas no *Snatch*, *Snatch Pull* e *Back Squat* (respetivamente, p=0,006 e ES=1,227; p=0,002 e ES=1,512; p=0,001 e ES=1,679), na velocidade máxima revelaram-se diferenças significativas no *Snatch*, *Snatch Pull* e *Back Squat* (respetivamente, p=0,002 e ES=1,469; p=0,005 e ES=1,258; p<0,001 e ES=2,058), relativamente a variável velocidade média este grupo mostrou diferenças significativas no *Snatch*, *Snatch Pull* e *Back Squat* (respetivamente, p=0,006 e ES=1,228; p=0,003 e ES=1,372; p=0,001 e ES=1,660), no grupo masculino, encontramos diferenças no ROM do *Snatch Pull*, *C&J* e *Clean* (respetivamente, p=0,042 e ES=0,663; p=0,004 e ES=1,033; p=0,020 e ES=0,786), foram apenas encontradas diferenças significativas na potência média no *C&J* (p=0,009 e ES=0,910), na velocidade máxima o grupo revelou diferenças significativas no *Power Snatch*, *Snatch* e *Snatch Pull* (respetivamente, p=0,009 e ES=0,910; p=0,025 e ES=0,745; p=0,039 e ES=0,675), a velocidade média apresentou diferenças significativas apenas no C&J (p=0,011 e ES=0,876). Concluiu-se que existem diferenças na indução de fadiga entre a maioria dos exercícios analisados e que o género feminino parece ser mais resistente à fadiga que o género masculino, relativamente aos exercícios derivados do *C&J*. No entanto nos exercícios derivados do *Snatch* o inverso parece acontecer na maioria das variáveis, exceto na velocidade máxima, em que ambos os géneros apresentam fadiga similar nos exercícios analisados.

Palavras-chave: Halterofilismo; Fadiga; Arremesso; Arranco; Agachamento; movimentos derivados.

Abstract

Title: Comparison between Olympic weightlifting exercises and derivatives for fatigue impact quantification

Load management is an extremely important subject in the control of fatigue and adaptation process in almost all sports. In Olympic Weightlifting (OW), some of the load variables are known, namely intensity and volume. However, the type of exercise remains unknown in specific terms because empiricism tells us that some exercises induce greater fatigue than others, nonetheless we do not know specifically the value for this quantification. Thus, this work intended to evaluate the amount of fatigue caused by various types of OW exercises. We resorted to an experimental quantitative design, where we induced fatigue in adult individuals with weightlifting experience of at least 2 years, through the execution of a set of 10 of the most used exercises in OW, in which the intensity and volume between them were equalized (4 sets of 3 repetitions), after which a Snatch Pull test was performed and changes in maximum and medium velocity, range of motion and medium power were evaluated as fatigue measurement, between before and after the protocol of each exercise through the linear transductor Vitruve (Vitruve encoder; Madrid, Spain).

Nine women and twelve men have participated in the study (age, 29.67±5.74years and 28.17±5.06years; height, 158.78±6.70cm and 174.50±6.07cm; body weight, 60.84±7.34kg and 79.46±5.32kg; %body fat, 17.76±7.63% and 16.98±5,14%, respectively). For the total sample, significant differences were found in the range of motion (ROM) of Snatch Pull, Snatch and Back Squat ($p<0.001$ and Effect Size (ES)=0.986; $p=0.003$ and ES=0.731; $p=0.021$ and ES=0.547, respectively) and also on Clean & Jerk (C&J) ROM ($p=0.015$ and ES=0.582), in the mean power variable, significant differences were found in Power Snatch, Snatch, Snatch Pull and Back Squat and C&J ($p=0.043$ and ES=0.472; $p=0.048$ and ES=0.460; $p=0.003$ and ES=0.729; $p=0.009$ and ES=0.636 ; $p=0.037$ and ES=0.488, respectively), in peak velocity, significant differences were found in Power Snatch, Snatch, Snatch Pull and Back Squat ($p=0.008$ and ES=0.638; $p<0.001$ and ES=0.998; $p<0.001$ and ES=0.906; $p<0.001$ and ES=0.906, respectively), in the mean velocity variable, significant differences were found in Snatch Pull and Back Squat ($p=0.030$ and ES=0.509; $p=0.003$ and ES=0.727, respectively). When genders were analysed separately, on the female group, significant differences were noticed in Snatch ROM, Snatch Pull and Back Squat ($p=0.006$ and ES=1.218; $p=0.001$ and ES=1.776; $p=0.002$ and ES=1.474, respectively), in the mean power variable, significant differences were found in Snatch, Snatch Pull and Back Squat (p=0.006 and ES=1.227; p=0.002 and ES=1.512 ; p=0.001 and ES=1.679, respectively), at peak velocity significant differences were revealed in Snatch, Snatch Pull and Back Squat (p=0.002 and ES=1.469; p=0.005 and ES=1.258; $p<0.001$ and ES=2.058, respectively), for the mean velocity variable, significant differences were found in Snatch, Snatch Pull and Back Squat (p=0.006 and ES=1.228; p=0.003 and ES=1.372 ; p=0.001 and ES=1.660, respectively). In the male group, differences were found in the ROM of Snatch Pull, C&J and Clean (p=0.042 and ES=0.663; p=0.004 and ES=1.033; p=0.020 and ES=0.786, respectively) also, significant differences in mean power were only found in C&J (p=0.009 and ES=0.910, at peak velocity were revealed significant differences in Power Snatch, Snatch and Snatch Pull (p=0.009 and ES=0.910; p=0.025 and ES=0.745; p=0.039 and ES=0.675, respectively), the mean velocity showed significant differences only in the C&J (p=0.011 and ES=0.876). It was concluded that there are differences in the induction of fatigue between most of the exercises analysed, and that the female gender seems to be more resistant to fatigue than the male gender, in relation to exercises derived from C&J, however in the exercises derived from Snatch the reverse seems to happen in most variables except at maximum speed, in which both genders present similar fatigue in the analysed exercises.

Keywords*:* Olympic Weightlifting; Fatigue; Clean & Jerk; Snatch; Squat; weightlifting derivatives.

1. Introduction

Olympic Weightlifting (OW) is a dynamic strength and power sport in which two complex lifts/exercises are performed in competition: the “Snatch” and the “Clean and Jerk” (C&J). During these lifts, weightlifters have achieved some of the highest peak power outputs reported in the literature (Garhammer, 1993; Garhammer & Mclaughlin, 1980). The Snatch requires the weighted barbell to be lifted from the floor (usually using a wide grip) to an overhead position in one continuous movement (Derwin, 1990), the C&J is divided in two main phases in which the first requires the barbell to be raised from the floor (using a shoulder width grip) to the front of the shoulders in one continuous movement (Al-Khleifat et al., 2019) and the second phase, the jerk the barbell is propelled from the shoulders to arm’s length overhead by the forces produced primarily by the hips and thighs (Grabe & Widule, 1988). Considering that weightlifting in its various forms creates the potential of strength for all sports, we must ask how to train weightlifting efficiently and how is it reflected in other sports? The answer to these questions may be to refine testing and training methods of weightlifting exercises and their derivatives (Králová et al., 2020).

Weightlifting exercises and their derivatives exercises (e.g. Hang Clean, Hang Snatch, Power Clean, Power Snatch, High Pull) have become a popular training modality to improve physical attributes underpinning performance across a range of sports (Ebben, 2009; Ebben et al., 2009; Simenz et al., 2005), largely owing to the high strength and power expressions during the movements (Hori et al., 2005) Monitoring, planning and periodizing load are critical factors when it comes to the athlete's development and progression. There has been an attempt by science to increasingly identify the variables of training, to control them. In fact, in the past even the successful Bulgarian methodology tried to reduce some variables, with the reduction of the variety of exercises used (Garhammer & Takano, 2003). However, it did not prove to be profitable in the long term, therefore there are still some factors that remain unknown.

In OW, training load variables such as volume (number of repetitions multiplied by the number of sets) are often manipulated. On the other hand, intensity, referred to the percentage of load (kilograms) extracted from the maximum repetitions of the main movements and in some cases they also use the total load, which is characterized by the number of sets multiplied by the number of repetitions multiplied by the kilograms lifted, also known as tonnage (Takano, 2012). The magnitude of force production and the capacity to perform a given amount of work as rapidly as possible are often suggested as primary underpinning qualities of sport skills.

Therefore, developing strength, power and speed capabilities are often primary aims of many athletic development programs (Morris et al., 2022).

Despite the variables that define the load are beginning to be well defined, namely in terms of intensity by volume (González-Badillo et al., 2006), there are several parallel factors that may still be associated with this quantification, namely the type and exercise selection (Badillo, 1991). More recently other algorithms for grouping and selection of exercises have been proposed, in some cases based on technical efficiency (Flores & Redondo, 2020).

Factors such as the number and type of muscle fibers involved, either because of the complexity of the movement, or because of the amount of force developed in a given unit of time, can vary in each exercise (Suchomel & Sole, 2017), thus creating an unknown additional fatigue.

Several researchers have highlighted strong relationships between load and movement velocity fatigue, with the assessment of strength qualities being load-velocity specific. Therefore, it is particularly important to know the fatigue induced by the different OW derivatives when programming the training load. It is crucial to know which exercises induce greater fatigue and its magnitude. High-power outputs and rate of force development expressed in weightlifting movements and derivatives (Garhammer & Mclaughlin, 1980), in conjunction with the motor control and coordination demands on the trunk and lower body muscles to stabilize and transmit forces (Eriksson et al., 2014), can effectively impact and compromise various aspects of an athlete’s load-velocity profile (Morris et al., 2022).This is a topic that has been scarce addressed in the literature, particularly in the production of results that may impact the approach the coach programs at this time, both in terms of exercise selection, and in terms of their distribution along the microcycles, mesocycles and macrocycles. Several attempts have already been made to try to organize the various exercises into clusters-approach (Takano, 2012), however the induction of fatigue was never the case.

In the present work, 10 of the most used exercises derivates of the OW were compared. A sample of 21 athletes performed, in a pre-randomized order, the 10 exercises with volumes and intensities equalized between them, within the 1 repetition maximum (1RM) of each athlete, also commonly known amongst OW lifters, to be their personal record. Before and after each trial a Snatch Pull test will be performed to monitor velocity, range of motion (ROM) and power as these variables, particularly velocity, seem to be a reliable indicator for fatigue quantification since they are highly correlated (R^2=0.98) (González-Badillo & Sánchez-Medina, 2010). Through data processing, it is intended to understand if there is a correlation between the variable’s variation and the type of exercise.

1.1. Framework

The OW has in its essence some specific variables that make it unique, namely, the ballistic characteristic of its movements (Suchomel et al., 2017), its ability to be one of the sports with the greatest power production (Garhammer, 1993), the versatility and range of its movements, and derivatives in the representation of the force-velocity curve (Suchomel et al., 2017). The exercises derived from the OW movements are frequently used in physical preparation in various sports due to all these characteristics (Ebben & Blackard, 2001; Ebben et al., 2004; Gee et al., 2011; Simenz et al., 2005; Slovak et al., 2019; Weldon et al., 2020) and particularly on its kinetic transfer to most sports through triple extension (ankles, knees and hips extension) (Canavan et al., 1996; Carlock et al., 2004; Garhammer & Gregor, 1992; Hori et al., 2008).
The quantification of fatigue from the various OW movements is important in the OW programming and periodization of training load as well as in other sports. The correct periodization of intensity and volume, as well as the exercise selection itself is essential to sporting success (Bompa & Buzzichelli, 2015).

1. Exercise Choice

The choice of exercises were based on the diversity of their capacity in the development of physical abilities (Suchomel et al., 2017), as well as their diversity and ability to solve key technical problems, the relationship between load ratio that some have among them, and the exercise frequency applied by OW coaches (Everett, 2009).

2. Snatch Pull Test

Usually, the isometric mid-thigh pull test (IMTP) is a popular, effective, and reliable way to test maximal strength in adult athletes. Administering a partial movement test is a safer and more time-efficient method than traditional 1RM testing. The IMTP produce itself relatively little fatigue and possesses a low potential for injury (Stone et al., 2019), but it proved to be less effective in predicting the competitive performance of OW than other tests (Travis et al., 2018). As stated by Stone et al. (2019), the IMTP is particularly useful, both for regularly athletes monitoring as well as for research purposes. Although there is some overlap, training monitoring can be divided into fatigue management and program efficacy. However, when considering the

concept of neuromuscular fatigue, it is important to note that isometric versus dynamic measurements don’t provide the same results. Additionally, bar ROM also plays an important role in OW, and it seems to be an important factor when assessing fatigue (Cheng & Rice, 2005). Therefore, we opted by the Snatch Pull Test (SPT) as a reference measure, which has been correlated with the Personal Record of the Snatch exercise (r=0.99) (Sandau et al., 2021), using the Isoinertial Dynamometer Vitruve (Vitruve encoder; Madrid, Spain) (previously Speed4Lifts), to measure (Pérez Castilla et al., 2019). Moreover, these type of tests can regularly be applied during weightlifting training as a valid alternative to the personal record Snatch test to assess individualized progression in weightlifting performance over time (Sandau et al., 2021).
Considering the fact that all these lifts have a correlation intensity with each other and Muscle Snatch is referenced as 60 to 65% of the Snatch PR, the intensity load of 60% was chosen, was based on (Everett, 2009). Therefore, setting it as baseline intensity, the volume chosen (4 sets of 3 repetitions) was the amount of load that is usually performed by lifters within the intensity already settled.

1.2. Problem Presentation

Knowing and controlling the maximum number of variables is essential for a better training schedule. Programming in OW based only on volume and intensity while leaving aside the value that each exercise complexity specifically can input, whether at the peripheral fatigue, whether central fatigue level, would be leaving part of this control to sheer chance. Currently, exercise selection is most often associated with technical objectives, based on the specificity of each movement, or specifically, associated with the training of the various physical abilities according to the strength-speed curve and the athlete’s needs, taking into account their weaknesses (Newton & Dugan, 2002).
In recent years, a considerable amount of research has been devoted to the study of the velocity-based training and its effect on strength (González-Badillo et al., 2014). The effect on fatigue assessment has also been studied (Pareja-Blanco et al., 2017; Sánchez-Medina & González-Badillo, 2011). Furthermore, it has also been observed that some authors dedicated to the segmentation and classification of weightlifting movements. As to its ability to train the various moments of the force-velocity curve represented as power-time curve (Suchomel & Sole, 2017), but as far as we know, there is a gap of research on the quantification of fatigue for each exercise.

In weightlifting, the velocity is regulated and should be replicated, according to the type of exercise and individual. However, the bar displacement additionally associated with the lifter height, creates a different and adequate successful execution velocity. Thus, the velocity is directly proportional to the bar displacement (Roman, 1974). This means, each exercise has an associated velocity of movement and a known mass (bar mass). Thereafter, it still remains unclear the degree of fatigue induction of each exercise or groups of exercises.

1.3. Objectives

The aim of this research was to compare several Olympic weightlifting exercise derivatives in order to understand each one's level of impact in overall fatigue, which can be therefore used when programming training sessions, additionally to the current load assessment, namely, intensity and volume, using the SPT.

1.4. Hypothesis

H0- when volume and intensity are equated, there are no differences between fatigue induced by OW exercises.

H1- when volume and intensity are equated, there are differences between fatigue, induced by OW exercises.

2. Methodology

2.1. Study Type

2.1.1. Experimental Research of Repeated Measures Design

This was a cross-sectional study that was divided in two separated days, spread by a minimum of three days and/or a maximum of five days apart, due to the great number of exercises on only one day, which could induce too much accumulated fatigue to the other exercises.

Internal validity was defined as the extent to which the observed results represent a truth for the sample being studied, and therefore, due to methodological errors, to increase internal validity, we ensured careful planning, control of adequate quality and implementation strategies such as turning volume and intensity constant in all exercises, including appropriate recruitment strategies such as including criteria, data collection, data analysis and sample size. This way, it's safe to say that methodological errors were minimized, procedures were recorded for future consult at protocols.io website (https://www.protocols.io/edit/untitled-protocol-cc87szzn), and the sample represents more than 10% of the OW Portuguese population (Federação de Halterofilismo de Portugal, 2021).

Regarding external validity, it was also suggested that other OW population in other countries can relate to results within the same sample size, although future studies are required.

Measures and Variables:

All data was collected and registered in excel sheet in which the following variables were used:

Anthropometric measures:

- Weight (kgs)
- Height (m)
- Fat (%)
- Fat Free Mass (kg)

Weightlifting variables:

- Peak Velocity (m/s)
- Mean Velocity (m/s)
- ROM (cm)

– Mean Power (w)

2.2. Participants

A sample of 21 Caucasians individuals, 12 males and 9 females participated in the study. To calculate the sample size, for the difference between two dependent means (*Paired sample T-test*), we adopted an effect size of 0.8, an alpha of 0.05 and beta of 0.95. The sample size was determined by the G-power - Statistical Power Analyses software for Windows (RRID: SCR_013726) (Faul et al., 2009) in which the result was n=19. Such sample size would provide a 96% of sample power. The characteristics of the participants are presented in table 1, which serves merely for participants description.

Table 1. Participants characteristics.

	Age (Years)	**Height** (cm)	**Weight** (kg)	**BFP** (%)	**FFM** (kg)
Female	29.7±5.7	158.8±6.7	60.8±7,3	17.8±7.6	48.9±7.7
Male	28.1±5.0	174.5±6.0	79.5±5.3	17.0±5.1	65.9±5.0
Total	28.8±5.3	167.8±10.1	71.5±11.2	17.3±6.2	58.6±10.6

BFP, body fat percentage; FFM, fat free mass.

This research took place at each participants usual training gym. Moreover, athletes participated voluntarily and only after signing the informed consent form (document copy in appendix). Then, they were familiarized with all procedures before data collection. The information collected was registered and saved on a single hard disk in order to ensure that the confidentiality of the participants data is in accordance with the indications of the National Data Protection Commission, it is certified, in any case, that the identification of the participants will never be made public and it is guaranteed that the contacts will be processed in an environment of privacy and not transferable to third parties. After collecting the data in an Excel file, a code is assigned to each participant and all elements, physical or digital, of nominal identification or contact details of the participants are eliminated.

This study was designed according to the recommendations of the World Medical Association's Declaration of Helsinki of 1975, as revised in 2013, for human studies and approved by the Ethics Committee of the Polytechnic Institute of Santarém, approval number: 07A-2021ESDRM (document copy in appendix).

Participants Eligibility Criteria

The following inclusion criteria was adopted: age between 18 and 40 years old, with more than 2 years of OW training, competing at national level and having between 61 and 96 kgs bodyweight for the male group, and between 49 and 71 kgs bodyweight for the female group, as these interval bodyweights were representative of about 95% of the current Portuguese OW lifters (Federação de Halterofilismo de Portugal, 2021), all participants that did not participate in any test/exercise were excluded from the study.

2.3. Materials and Equipment

2.3.1 Instruments

Table 2 presents all instruments/equipments used in the present work.

Table 2. Instruments.

Instrument description	Number of units	Brand and model
Isoinertial Dynamometer 1Khz	1	Vitruve (formerly named speed4lifts)
Isoinertial sensor	1	Beast
Bioimpedance equipment	1	InBody S10 equipment (Model JMW140, Biospace Co, Ltd, Seoul, Korea)
Stadiometer/scale	1	SECA 220, Germany, Hamburg
20 Kilograms Olympic Barbell	1	Semperfit
15 Kilograms Olympic Barbell	1	Semperfit
25 kilograms Olympic Plates	4	Semperfit
20 Kilograms Olympic Plates	2	Semperfit
15 Kilograms Olympic Plates	2	Semperfit
10 Kilograms Olympic Plates	2	Semperfit
5 Kilograms Plates	2	Semperfit
2,5 Kilograms Plates	2	Semperfit
2 Kilograms Plates	2	Semperfit
1,5 Kilograms Plates	2	Semperfit
1 Kilogram Plates	2	Semperfit
0,5 Kilogram Plates	2	Semperfit
2,5 Kilogram Olympic Collars	2	Semperfit
Straps	2	Unbranded
Tripods	3	Unbranded
Smartphone	2	Huawei p Smart Pro
Tablet	1	Ipad 128Mb
Laptop personal computer	1	Dell Latitude E6430
Pen	5	BIC
A5 Textbook	3	Unbranded
Statistics software	1	IBM SPSS v28.0 statistics software

2.3.2. Resources

Human resources:

Two certified strength and conditioning professional performed the anthropometric data collection, as well as the implement of the training protocol with consequently further data collection.

Facility Resources:

Sports Sciences School of Rio Maior, Gym 1, Crossfit 4475, Move On Crossfit, Off Limits Crossfit, Coimbra Functional Fitness, Crossfit Leiria, Line up Crossfit and Fitbox 4500 Espinho for training protocol execution and data collection.

2.4. Training Protocol and Procedures

Procedures:

Familiarization

Participants started by the anthropometric assessment, namely, height, weight and bioimpedance assessment. After that the explanation and familiarization with the protocol was provided.

Anthropometric and Body Composition Assessment

The anthropometric and body composition measures were obtained with the subjects dressed in light clothing without shoes following previous recommendations (Arazi et al., 2015) through a stadiometer with an incorporated scale (Seca 220, Hamburg, Germany) according to standardized procedures (Lohman et al., 1988). The body composition data were obtained with bioelectrical impedance analysis through Inbody S10 (model JMW140, Biospace Co, Ltd., Seoul, Korea), according to manufacturer's guidelines (Buckinx et al., 2015; Yang et al., 2017). Eight electrodes were placed on eight tactile points (thumbs, middle fingers and ankles of both hands and feet, respectively) to perform the multi-segmental frequency analysis. The variables collected were body fat mass (BFM) and fat-free mass (FFM).

The measurements were carried out in the morning, in a room with an ambient temperature and relative humidity of 22–23 °C and 50–60%, respectively, after a minimum of 8 h of fasting and after the bladder was emptied following previous suggestions (Arazi et al., 2015; Rahmat et al., 2016). The participants adopted a supine position with their arms and legs abducted at a 45◦ angle, and the right hand and foot dorsal surfaces were cleaned with alcohol. After a 10 min rest in a room without noise, eight electrodes were placed on the cleaned surfaces and the measurements were performed.

Before data collection, participants did not exercise or ingest caffeine or alcohol during the 12 h prior to the assessment. In addition, participants removed all objects that could interfere with the bioelectrical impedance assessment.

Female participants were only assessed if they were in the luteal phase of ovulatory menstrual cycles. Otherwise, they waited for more days, until they were in the luteal phase. All the assessments were performed by the same evaluator to minimize possible measurement errors (Marfell-Jones et al., 2012).

Protocol Test

A standardized 10-minute warm-up including, mobility exercises, several OW repetitions and jumps was carried out to all experimental groups before the beginning of each training session, to minimize the risk of injury, additionally there were always two assistants to monitor exercise execution.

Participants started their personal warm-up exercise/specific for training session up to 60% of the Snatch 1RM, followed by two 50%, one 70% and one at 100% of Snatch 1RM, SPT attempts separated by 1 minute recovery, verbal feedback and technical advice will be given by coaches, if necessary, before each SPT verbal instruction cues were given in a standardized form, namely: “Pull hard and fast.”

On the first day Snatch and Derivatives protocol took place, after the warm-up, the baseline SPT evaluation took place (figure 1), making 1RM of Snatch personal record after which data was collected. Then participants rested 1 minute followed by the Muscle Snatch protocol, of 4 sets of 3 repetitions, at 60% of the Snatch 1RM (1 minute rest between sets). After the protocol, participants then took 1 minute rest before the post muscle Snatch SPT evaluation (1RM).

Followed by the Power Snatch protocol, of 4 sets of 3 repetitions, at 60% of the Snatch 1RM (1 minute rest between sets), after the protocol, participants then took 1 minute rest before the post Power Snatch SPT evaluation, also one repetition at 100% Snatch 1RM after which data was collected, participants would then rest 1 minute.

Followed by the Snatch protocol, of 4 sets of 3 repetitions, at 60% of the Snatch 1RM (1 minute rest between sets), after the protocol, participants would then take 1 minute rest before the post Snatch SPT evaluation, also one repetition at 100% Snatch 1RM after which data would be collected, participants would then rest 1 minute.

Followed by the Snatch Pull protocol, of 4 sets of 3 repetitions, at 60% of the Snatch 1RM (1 minute rest between sets), after the protocol, participants would then take 1 minute rest before the post Snatch Pull SPT evaluation, also one repetition at 100% Snatch 1RM after which data would be collected, participants would then rest 1 minute.

Followed by the Back Squat protocol, of 4 sets of 3 repetitions, at 60% of the Snatch 1RM (1 minute rest between sets), after the protocol, participants would then take 1 minute rest before the post Back Squat SPT evaluation, also one repetition at 100% Snatch 1RM after which data would be collected.

On the second test day, three days after the tests were performed in the Snatch derivatives exercises, was time for the C&J and derivative exercises protocol, therefore, participants started their personal warm-up exercise/specific for training session up to 60% of 1RM (C&J), followed by two 50%, one 70% and one at 100% of Snatch 1RM, SPT attempts separated by 1 minute recovery. Feedback and technical advice were given by coaches, if necessary, before each SPT verbal instruction cues were also be given, namely: “Pull Hard and Fast.”.

After the warm-up, the baseline SPT Evaluation took place, making one repetition at 100% of Snatch 1RM after which data was collected, participants would then rest 1 minute, followed by the Power Clean protocol, of 4 sets of 3 repetitions, at 60% of the C&J 1RM (1 minute rest between sets), after the protocol, participants would then take 1 minute rest before the post Power Clean SPT evaluation, also one repetition at 100% Snatch 1RM after which data would be collected, participants would then rest 1 minute.

Followed by the C&J protocol, of 4 sets of 3 repetitions, at 60% of the C&J 1RM (1 minute rest between sets), after the protocol, participants would then take 1 minute rest before the post C&J SPT evaluation, also one repetition at 100% Snatch 1RM after which data was collected, participants would then rest 1 minute.

Followed by the Clean protocol, of 4 sets of 3 repetitions, at 60% of the C&J 1RM (1 minute rest between sets), after the protocol, participants would then take 1 minute rest before the post Clean SPT evaluation, also one repetition at 100% Snatch 1RM after which data would be collected, participants would then rest 1 minute.

Followed by the High Hang Clean protocol, of 4 sets of 3 repetitions, at 60% of the C&J 1RM (1 minute rest between sets), after the protocol, participants would then take 1 minute rest before the post High Hang Clean SPT evaluation, also one repetition at 100% Snatch 1RM after which data would be collected, participants will then rest 1 minute.

Followed by the Hang Power Clean protocol, of 4 sets of 3 repetitions, at 60% of the C&J 1RM (1 minute rest between sets), after the protocol, participants would then take 1 minute rest before the post Hang Power Clean SPT evaluation, also one repetition at 100% Snatch 1RM after which data would be collected.

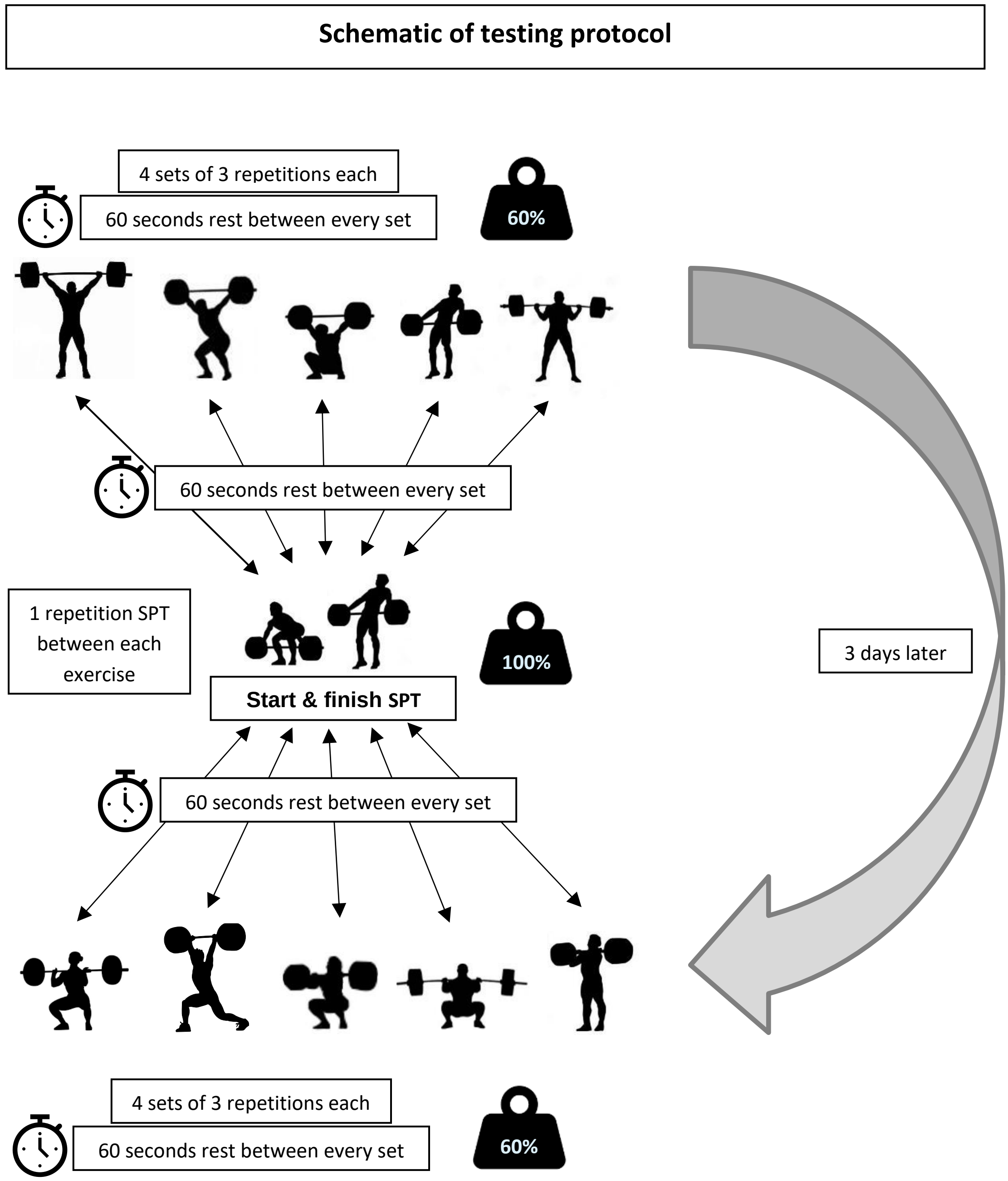

Figure 1-Schematic of Snatch, C&J and derivatives testing protocol.

2.5 Statistical Analysis

All statistical analysis were performed using IBM SPSS for Windows (IBM Corp. Released 2020., Version 28.0. Armonk, NY, USA). Data was described by means ± standard deviation (SD), standard error of the mean (SEM) and mean difference (MD) with 95% of confidence interval (CI). Then, to verify the normality, Shapiro-Wilk test was used (groups under n<50). Differences between exercise fatigue were examined using the T test for paired samples (velocity change; range of motion change; mean power change within each type of exercise monitored, using the isoinertial dynamometer). A $p < 0.05$ was considered significative and a percentage change with 95% CI were also calculated. Finally, effect size calculation, the Cohen's d was used according to the following thresholds: large d > 0.8, moderate d between 0.8 and 0.5, small d between 0.49 and 0.20, trivial d < 0.2 (Cohen, 2013).

2.6 Variable Operating Plan

Table 3 presents all dependent variables used in the study.

Table 3. Variable operating plan.

Variables	Units	Scale
Peak Velocity	m/s	Continuous
Mean Velocity	m/s	Continuous
Range of motion	cm	Continuous
Mean power	w	Continuous

3. Results

In the data collections there was no dropout, all subjects completed all the testing and exercise protocols.

3.1. Snatch derivative protocols

Mean power variable

When analysing the entire sample, we have found that after the Muscle Snatch protocol, mean power did not show a significant difference while Power Snatch, Snatch, Snatch Pull and Back Squat showed a significant difference (Table 4). However, when considering the gender groups separately, female group (N=9) shows that after the Muscle Snatch and Power Snatch protocol did not present significant difference, whereas, Snatch, Snatch Pull and Back Squat showed a significant difference. As for the male group (N=12), we found that mean power did not show a significant difference in any exercise.

Mean velocity variable

For total sample (N=21), we have found that only Snatch and Back Squat showed a significant difference (Table 4). When gender groups are separated, female group showed that after the Muscle Snatch and Power Snatch both did not present a significant difference (Table 5), whereas, Snatch, Snatch Pull and Back Squat all showed a significant difference. As for the male group, none of the exercises showed a significant difference in mean velocity.

Peak velocity variable

For the total sample (N=21) and after the Muscle Snatch protocol, peak velocity did not show a significant difference (Table 4), whereas Power Snatch, Snatch, Snatch Pull and Back Squat they all showed a significant difference.

Female group did not show a significant difference after the Muscle Snatch and Power Snatch protocol, whereas, Snatch, Snatch Pull and Back Squat showed a significant difference (Table 5). No differences were found for the male group in Muscle Snatch and Back Squat. However, significant differences were found in Power Snatch, Snatch and Snatch Pull.

ROM variable

For the total sample (N=21), we have found that after the Muscle Snatch protocol, ROM did not exhibit a significant difference, also no significant difference found in Power Snatch, whereas in Snatch, Snatch Pull and Back Squat they all showed a significant difference (Table 4).

When gender groups are separated (Table 5), female group revealed that after the Muscle Snatch protocol, ROM did not express a significant difference, Power Snatch also did not reveal a significant difference, whereas, Snatch, Snatch Pull and Back Squat all presented a significant difference. As for the male group (N=12), we have found that there was only significative difference ROM change in Snatch Pull, all other exercises did not.

3.2. Clean & Jerk derivative protocols

Mean power variable

According to the *Paired sample T Test*, on the C&J exercises and considering all sample (N=21), we have found that after protocols, only C&J showed a significant difference (Table 6). However, when gender groups are separated, female group showed that mean power did not express a significant difference in any of the exercises. As for the male group, we have found that only C&J did show a significant difference (Table 7).

Mean velocity variable

Total sample (N=21), we have found that after protocols, mean velocity only showed a significant difference in C&J (Table 6). When gender groups were separated the female group (N=9), we have found that mean velocity hasn't showed a significant difference in any of the exercises. As for the male group (N=12), we have found that, only C&J showed significant differences (Table 7).

Peak velocity variable

We have found that regarding peak velocity, none of the exercises showed significant differences in any of the groups.

Range of Motion variable

Total sample (N=21), we have found that ROM did not show a significant difference in any of the exercises except for the C&J in which we found significant exercises (Table 6).

When gender groups are separated (N=9, female), we have found that none of the exercise showed a significant difference (Table 7).

As for the male group (N=12), we have found that there was no significative difference in the Power Clean, High Hang Clean and Hang Power Clean, whereas in C&J, and Clean, both showed significant differences.

Table 4. Baseline and post values of Snatch Pull Test on the Snatch derivatives (♀♂= 21).

Parameter		Weightlifting derivative	Mean±SD	SEM	MD (95%CI)	*p* (Effect Size)
ROM (cm)			Baseline			
		SPT	106.49±7.49	1.64		
			Post			
	Pair 1	Muscle_Snatch	107.33±7.75	1.69	-0.85 (-2.65; 0.95)	0.338 (-0.214)
	Pair 2	Power_Snatch	105.15±7.93	1.73	1.34 (-0.36; 3.04)	0.116 (0.358)
	Pair 3	Snatch	104.19±7.85	1.71	2.30 (0.87; 3.73)	0.003* (0.731)
	Pair 4	Snatch_Pull	102.82±8.63	1.88	3.67 (1.97; 5.36)	<0.001** (0.986)
	Pair 5	Back_Squat	103.97±9.41	2.05	2.52 (0.42; 4.62)	0.021* (0.547)
Mean Power (w)			Baseline			
		SPT	706.55±187.58	40.93		
			Post			
	Pair 1	Muscle_Snatch	701.93±189.80	41.42	4.61 (-18.41; 27.64)	0.680 (0.091)
	Pair 2	Power_Snatch	681.19±181.14	39.53	25.36 (0.93; 49.79)	0.043* (0.472)
	Pair 3	Snatch	677.11±183.49	40.04	29.44 (0.32; 58.55)	0.048* (0.460)
	Pair 4	Snatch_Pull	664.41±180.76	39.44	42.14 (15.84; 68.44)	0.003* (0.729)
	Pair 5	Back_Squat	671.32±190.58	41.59	35.22 (10.03; 60.42)	0.009* (0.636)
Peak Velocity (m/s)			Baseline			
		SPT	1.81±0.17	0.04		
			Post			
	Pair 1	Muscle_Snatch	1.78±0.18	0.04	0.04 (-0.01; 0.09)	0.125 (0.350)
	Pair 2	Power_Snatch	1.76±0.19	0.04	0.06 (0.02; 0.10)	0.008* (0.638)
	Pair 3	Snatch	1.73±0.17	0.04	0.08 (0.05; 0.12)	<0.001** (0.998)
	Pair 4	Snatch_Pull	1.72±0.15	0.03	0.09 (0.05; 0.14)	<0.001** (0.906)
	Pair 5	Back_Squat	1.73±0.18	0.04	0.08 (0.04; 0.13)	<0.001** (0.906)
Mean Velocity (m/s)			Baseline			
		SPT	0.94±0.13	0.03		
			Post			
	Pair 1	Muscle_Snatch	0.93±0.12	0.03	0.01 (-0.02; 0.04)	0.508 (0.147)
	Pair 2	Power_Snatch	0.91±0.13	0.03	0.03 (0.00; 0.06)	0.050 (0.455)
	Pair 3	Snatch	0.90±0.13	0.03	0.04 (0.00; 0.07)	0.030* (0.509)

	Pair 4 Snatch_Pull	0.92±0.15	0.03	0.02 (-0.06; 0.10)	0.604 (0.115)
	Pair 5 Back_Squat	0.89±0.13	0.03	0.05 (0.02; 0.08)	0.003* (0.727)

SPT, Snatch Pull Test; ROM, Range of Motion; *, p<0.05; **, p<0.001; SD, standard deviation; SEM, Standard error of the mean.

In the assessment of the Snatch variables for total sample, we verified that ROM, post Snatch Pull protocol, as well as peak velocity, post Snatch, Snatch Pull and Back Squat, showed differences for p<0.001.

Table 5. Baseline and post values of Snatch Pull Test on the Snatch derivatives (♀=9; ♂n= 12).

Parameter		Weightlifting derivative	Mean±SD	SEM	MD (95%CI)	*p* (Effect Size)
ROM (cm)	Female		Baseline			
		SPT	105.22±8.25	2.75		
			post			
		Pair 1 Muscle_Snatch	105.16±9.00	3.00	0.07 (-2.18; 2.32)	0.947 (0.023)
		Pair 2 Power_Snatch	104.58±9.29	3.10	0.64 (-1.95; 3.23)	0.585 (0.189)
		Pair 3 Snatch	102.04±9.17	3.06	3.18 (1.17; 5.18)	0.006* (1.218)
		Pair 4 Snatch_Pull	100.40±10.44	3.48	4.82 (2.73; 6.91)	0.001* (1.776)
		Pair 5 Back_Squat	100.03±10.91	3.64	5.19 (2.48; 7.90)	0.002* (1.474)
	Male		Baseline			
		SPT	107.43±7.10	2.05		
			post			
		Pair 1 Muscle_Snatch	108.97±6.59	1.90	-1.53 (-4.45; 1.38)	0.272 (-0.334)
		Pair 2 Power_Snatch	105.57±7.16	2.10	1.87 (-0.71; 4.44)	0.139 (0.460)
		Pair 3 Snatch	105.79±6.66	1.92	1.64 (-0.55; 3.84)	0.128 (0.475)
		Pair 4 Snatch_Pull	104.63±6.91	2.00	2.80 (0.11; 5.49)	0.042* (0.663)
		Pair 5 Back_Squat	106.91±7.23	2.09	0.52 (-2.28; 3.32)	0.692 (0.117)
Mean Power (w)	Female		Baseline			
		SPT	557.79±128.94	42.98		
			post			
		Pair 1 Muscle_Snatch	540.79±113.25	37.75	17.00 (-0.81; 34.81)	0.059 (0.734)
		Pair 2 Power_Snatch	536.32±121.34	40.45	21.47 (-4.20; 47.13)	0.090 (0.643)
		Pair 3 Snatch	521.19±113.48	37.83	36.60 (13.67; 59.53)	0.006* (1.227)
		Pair 4 Snatch_Pull	518.99±121.16	40.39	38.80 (19.07; 58.53	0.002* (1.512)
		Pair 5 Back_Squat	518.82±128.90	42.97	38.97 (21.13; 56.81)	0.001* (1.679)
	Male		Baseline			
		SPT	818,12±142.13	41.03		
			post			

		Pair 1	Muscle_Snatch	822.79±137.79	39.78	-4.68 (-45.08; 35.73)	0.804 (-0.074)
		Pair 2	Power_Snatch	789.84±137.47	39.68	28.28 (-13.89; 70.44)	0.168 (0.426)
		Pair 3	Snatch	794.05±130.53	37.68	24.07 (-28.01; 76.14)	0.331 (0.294)
		Pair 4	Snatch_Pull	773.47±135.84	39.21	44.65 (-2.79; 92.08)	0.063 (0.598)
		Pair 5	Back_Squat	785.70±143.73	41.49	32.42 (-13.22; 78.05)	0.146 (0.451)
Peak Velocity (m/s)	Female			Baseline			
		SPT		1.88±0.17	0.06		
				post			
		Pair 1	Muscle_Snatch	1.84±0.15	0.05	0.04 (-0.01; 0.09)	0.102 (0.615)
		Pair 2	Power_Snatch	1.86±0.16	0.05	0.02 (-0.04; 0.08)	0.422 (0.282)
		Pair 3	Snatch	1.78±0.15	0.05	0.10 (0.05; 0.16)	0.002* (1.469)
		Pair 4	Snatch_Pull	1.76±0.17	0.06	0.12 (0.05; 0.20)	0.005* (1.258)
		Pair 5	Back_Squat	1.74±0.21	0.07	0.14 (0.09; 0.20)	<0.001* (2.058)
	Male			Baseline			
		SPT		1.76±0.16	0.05		
				post			
		Pair 1	Muscle_Snatch	1.73±0.19	0.05	0.04 (-0.05; 0.12)	0.378 (0.265)
		Pair 2	Power_Snatch	1.68±0.18	0.05	0.09 (0.03; 0.14)	0.009* (0.910)
		Pair 3	Snatch	1.69±0.17	0.05	0.07 (0.01; 0.13)	0.025* (0.745)
		Pair 4	Snatch_Pull	1.69±0.14	0.04	0.07 (0.00; 0.14)	0.039* (0.675)
		Pair 5	Back_Squat	1.73±0.17	0.05	0.04 (-0.01; 0.09)	0.134 (0.467)
Mean Velocity (m/s)	Female			Baseline			
		SPT		0.99±0.14	0.05		
				post			
		Pair 1	Muscle_Snatch	0.97±0.13	0.04	0.03 (-0.00; 0.06)	0.063 (0.719)
		Pair 2	Power_Snatch	0.97±0.14	0.05	0.02 (-0.01; 0.06)	0.144 (0.540)
		Pair 3	Snatch	0.93±0.14	0.05	0.06 (0.02; 0.10)	0.006* (1.228)
		Pair 4	Snatch_Pull	0.92±0.11	0.04	0.07 (0.03; 0.11)	0.003* (1.372)
		Pair 5	Back_Squat	0.92±0.14	0.05	0.07 (0.04; 0.10)	0.001* (1.660)
	Male			Baseline			
		SPT		0.89±0.12	0.03		
				post			
		Pair 1	Muscle_Snatch	0.90±0.10	0.03	-0.01 (-0.05; 0.04)	0.806 (-0.073)
		Pair 2	Power_Snatch	0.86±0.11	0.03	0.03 (-0.02; 0.08)	0.174 (0.419)
		Pair 3	Snatch	0.87±0.12	0.03	0.02 (-0.04; 0.08)	0.412 (0.246)
		Pair 4	Snatch_Pull	0.91±0.18	0.05	-0.02 (-0.17; 0.13)	0.800 (-0.075)
		Pair 5	Back_Squat	0.86±0.13	0.04	0.03 (-0.02; 0.09)	0.174 (0.420)

SPT, Snatch Pull Test; ROM, Range of Motion; *, p<0.05; SD, standard deviation; SEM, Standard error of the mean.

In the assessment of Snatch variables by gender, differences were found for $p<0.05$.

On table 6. the results of the evaluation in the C&J protocol for the entire sample are presented.

Table 6. Baseline and post values of Snatch Pull Test on the Clean & Jerk derivatives (♀♂n= 21).

Parameter	Weightlifting derivative		Mean±SD	SEM	MD (95%CI)	*p* (Effect Size)
ROM (cm)			Baseline			
	SPT		106.01±8.00	1.75		
			post			
	Pair 1	Power Clean	105.77±7.91	1.73	0.24 (-0.91; 1.39)	0.671 (0.094)
	Pair 2	Clean & Jerk	103.91±8.88	1.94	2.10 (0.46; 3.73)	0.015* (0.582)
	Pair 3	Clean	104.67±8.77	1.91	1.34 (-0.27; 2.96)	0.098 (0.378)
	Pair 4	High_Hang_Clean	105.03±8.98	1.96	0.98 (-0.43; 2.38)	0.164 (0.316)
	Pair 5	Hang_Power_Clean	104.92±8.41	1.83	1.09 (-0.81; 2.99)	0.245 (0.261)
Mean Power (w)			Baseline			
	SPT		699.81±176.31	38.47		
			post			
	Pair 1	Power Clean	700.49±183.15	39.97	-0.68 (-16.10; 14.74)	0.928 (-0.020)
	Pair 2	Clean & Jerk	675.26±170.43	37.19	24.55 (1.65; 47.44)	0.037* (0.488)
	Pair 3	Clean	679.59±180.17	39.32	20.22 (-5.70; 46.14)	0.119 (0.355)
	Pair 4	High_Hang_Clean	690.40±178.72	39.00	9.41 (-16.66; 35.48)	0.460 (0.164)
	Pair 5	Hang_Power_Clean	687.63±176.81	38.58	12.18 (-13.46; 37.82)	0.334 (0.216)
Peak Velocity (m/s)			Baseline			
	SPT		1.75±0.16	0.03		
			post			
	Pair 1	Power Clean	1.75±0.17	0.04	-0.01 (-0.05; 0.04)	0.809 (-0.054)
	Pair 2	Clean & Jerk	1.74±0.18	0.04	0.01 (-0.02; 0.04)	0.456 (0.166)
	Pair 3	Clean	1.74±0.18	0.04	0.01 (-0.03; 0.04)	0.712 (0.082)
	Pair 4	High_Hang_Clean	1.74±0.16	0.03	0.01 (-0.02; 0.04)	0.511 (0.146)
	Pair 5	Hang_Power_Clean	1.75±0.15	0.03	0.00 (-0.03; 0.04)	0.819 (0.051)
Mean Velocity (m/s)			Baseline			
	SPT		0.93±0.11	0.02		
			post			
	Pair 1	Power Clean	0.93±0.11	0.02	0.00 (-0.02; 0.02)	0.846 (0.043)
	Pair 2	Clean & Jerk	0.90±0.12	0.03	0.03 (0.00; 0.06)	0.050 (0.478)
	Pair 3	Clean	0.90±0.11	0.02	0.03 (-0.00; 0.06)	0.071 (0.415)
	Pair 4	High_Hang_Clean	0.91±0.11	0.03	0.01 (-0.02; 0.04)	0.358 (0.205)
	Pair 5	Hang_Power_Clean	0.91±0.11	0.02	0.02 (-0.01; 0.05)	0.227 (0.272)

SPT, Snatch Pull Test; ROM, Range of Motion; *, p<0.05; SD, standard deviation; SEM, Standard error of the mean.

After evaluating C&J variables for total sample, we have verified that unlike the Snatch one group evaluation, this time we have only two results <0.05 and no results <0.001.
The results of the C&J test assessment by gender are shown in table 7.

Table 7. Baseline and post values of Snatch Pull Test on the Clean & Jerk derivatives (♀n= 9; ♂n= 12).

Parameter		Weightlifting derivative		Mean±SD	SEM	MD (95%CI)	*p* (Effect Size)
ROM (cm)	Female			Baseline			
		SPT		102.14±6.68	2.23		
				post			
		Pair 1	Power Clean	102.77±7.98	2.66	-0.62 (-2.78; 1.54)	0.525 (-0.222)
		Pair 2	Clean & Jerk	101.93±8.16	2.72	0.21 (-2.16; 2.58)	0.843 (0.068)
		Pair 3	Clean	102.18±8.70	2.90	-0.03 (-3.03; 2.96)	0.980 (-0.009)
		Pair 4	High_Hang_Clean	102.03±8.87	2.96	0.11 (-2.42; 2.64)	0.922 (0.034)
		Pair 5	Hang_Power_Clean	101.47±7.26	2.42	0.68 (-1.42; 2.77)	0.477 (0.248)
	Male			Baseline			
		SPT		108.91±7.91	2.28		
				post			
		Pair 1	Power Clean	108.03±7.38	2.13	0.88 (-0.51; 2.28)	0.192 (0.401)
		Pair 2	Clean & Jerk	105.40±9.44	2.73	3.51 (1.35; 5.67)	0.004* (1.033)
		Pair 3	Clean	106.53±8.72	2.52	2.38 (0.46; 4.29)	0.020* (0.786)
		Pair 4	High_Hang_Clean	107.28±8.74	2.52	1.63 (-0.22; 3.47)	0.079 (0.559)
		Pair 5	Hang_Power_Clean	107.51±8.55	2.47	1.40 (-1.84; 4.64)	0.362 (0.275)
Mean Power (w)	Female			Baseline			
		SPT		536.97±100.78	33.59		
				post			
		Pair 1	Power Clean	539.52±125.88	41.96	-2.56 (-27.66; 22.55)	0.820 (-0.078)
		Pair 2	Clean & Jerk	539.18±132.05	44.02	-2.21 (-33.10; 28.63)	0.873 (-0.055)
		Pair 3	Clean	533,22±130.91	43.64	3.74 (-26.22; 33.70)	0.781 (0.096)
		Pair 4	High_Hang_Clean	542.37±125.61	41.87	-5.40 (-27.63; 16.83)	0.591 (-0.187)
		Pair 5	Hang_Power_Clean	528.48±120.75	40,30	8.49 (-15.44; 32.41)	0.437 (0.273)
	Male			Baseline			
		SPT		821,94±105.66	30.50		
				post			
		Pair 1	Power Clean	821.21±111.21	32.10	0.73 (-22.23; 23.69)	0.945 (0.020)
		Pair 2	Clean & Jerk	777.33±116.69	33.68	44.62 (13.47; 75.76)	0.009* (0.910)

		Pair 3	Clean	789.37±126.03	36.38	32.58 (-9.58; 74.73)	0.117 (0.491)
		Pair 4	High_Hang_Clean	801.42±123.38	35.62	20.53(-24.59; 65.64)	0.338 (0.289)
		Pair 5	Hang_Power_Clean	806.99±99.85	28.82	14.95 (-30.17; 60.07)	0.481 (0.211)
Peak Velocity (m/s)	Female			Baseline			
		SPT		1.80±0.13	0.04		
				post			
		Pair 1	Power Clean	1.80±0.15	0.05	-0.01 (-0.10; 0.05)	0.795 (-0.090)
		Pair 2	Clean & Jerk	1.82±0.12	0.04	-0.02 (-0.06; 0.02)	0.231 (-0.081)
		Pair 3	Clean	1.81±0.15	0.05	-0.01 (-0.07; 0.05)	0.725 (-0.121)
		Pair 4	High_Hang_Clean	1.79±0.15	0.05	0.01 (-0.06; 0.07)	0.849 (0.066)
		Pair 5	Hang_Power_Clean	1.77±0.16	0.05	0.03 (-0.04; 0.10)	0.377 (0.312)
	Male			Baseline			
		SPT		1.72±0.17	0.05		
				post			
		Pair 1	Power Clean	1.72±0.18	0.05	-0.00 (-0.08; 0.07)	0.903 (-0.036)
		Pair 2	Clean & Jerk	1.68±0.20	0.06	0.04 (-0.01; 0.08)	0.089 (0.539)
		Pair 3	Clean	1.70±0.19	0.05	0.02 (-0.03; 0.07)	0.437 (0.233)
		Pair 4	High_Hang_Clean	1.70±0.16	0.05	0.01 (-0.03; 0.05)	0.459 (0.222)
		Pair 5	Hang_Power_Clean	1.73±0.15	0.04	-0.02 (-0.06; 0.03)	0.492 (-0.205)
Mean Velocity (m/s)	Female			Baseline			
		SPT		0.96±0.12	0.04		
				post			
		Pair 1	Power Clean	0.96±0.12	0.04	0.00 (-0.04; 0.04)	0.901 (0.043)
		Pair 2	Clean & Jerk	0.96±0.12	0.04	0.01 (-0.04; 0.06)	0.773 (0.099)
		Pair 3	Clean	0.95±0.11	0.04	0.02 (-0.04; 0.07)	0.493 (0.239)
		Pair 4	High_Hang_Clean	0.96±0.11	0.04	-0.00 (-0.04; 0.04)	0.947 (-0.023)
		Pair 5	Hang_Power_Clean	0.94±0.11	0.04	0.02 (-0.03; 0.07)	0.322 (0.352)
	Male			Baseline			
		SPT		0.90±0.10	0.03		
				post			
		Pair 1	Power Clean	0.90±0.10	0.03	0.00 (-0.02; 0.03)	0.890 (0.041)
		Pair 2	Clean & Jerk	0.86±0.10	0.03	0.05 (0.01; 0.08)	0.011* (0.876)
		Pair 3	Clean	0.86±0.10	0.03	0.04 (-0.01; 0.08)	0.091 (0.535)
		Pair 4	High_Hang_Clean	0.88±0.11	0.03	0.02 (-0.02; 0.07)	0.282 (0.326)
		Pair 5	Hang_Power_Clean	0.89±0.11	0.03	0.01 (-0.03; 0.06)	0.489 (0.207)

SPT, Snatch Pull Test; ROM, Range of Motion; *, p<0.05; SD, standard deviation; SEM, Standard error of the mean.

4. Discussion

The study' aim was to measure fatigue between ten of the most used weightlifting derivatives exercises, using several variables (ROM, mean velocity, peak velocity, and mean power), in national level OW athletes. The majority of these exercises are also used not only in OW, but in general fitness preparation and strength and conditioning training programs (Ebben et al., 2004; Ebben & Blackard, 2001; Gee et al., 2011; Simenz et al., 2005; Weldon et al., 2020).

The main results showed that for the total sample, significant differences were found in the Snatch Pull, Snatch and Back Squat ROM and also on C&J ROM. Regarding the mean power variable, significant differences were found in power Snatch, Snatch, Snatch Pull and Back Squat and C&J. Regarding peak velocity, significant differences were found in power Snatch, Snatch, Snatch Pull and back squat. Regarding the mean velocity variable, significant differences were found in Snatch Pull and back squat.

When genders were analysed separately, on the female group, significant differences in Snatch ROM, Snatch Pull and Back Squat were noticed while in the male group, differences were found in the ROM of Snatch Pull, C&J and clean. Regarding the mean power variable of the female group, significant differences were found in Snatch, Snatch Pull and Back Squat while in the male group, significant differences in mean power were only found in C&J. Regarding peak velocity, the female group revealed significant differences in Snatch, Snatch Pull and Back Squat while the male group revealed significant differences in power Snatch, Snatch and Snatch Pull. Regarding mean velocity variable, the female group showed significant differences in Snatch, Snatch Pull and Back Squat (while the male group only showed significant differences in the C&J. Considering all sample (female and male), almost all variables presented significant differences as well as moderate-to-large effect sizes values. Peak velocity seemed to present the most significant differences in both groups, however on the female group, Snatch derivatives seemed to show significant differences in every variable studied. On the other hand, the male group only showed significant differences in peak velocity. The only exercise that did not show any difference in any variable is Muscle Snatch, which presented the highest ROM. Higher barbell ROM have a dependent relationship with the subjects' height (Roman, 1974; Suchomel et al., 2017; Suchomel et al., 2020; Suchomel & Sole, 2017), meaning that if the lifter is taller, the barbell needs to have a higher displacement than if the lifter is shorter.

Due to the small number of tested athletes, it was not possible to divided them into individual weight categories and then perform a correlation analysis. In research of this sort, it is not common to evaluate the results of men and women together. The fact that we compared parameters in women and men as one homogeneous group could be considered questionable and should be considered as a limitation as well as avoided in future studies. This methodological decision stems from the practical issue, that trainers test both men and women together (Králová et al., 2019).

Recent research also reported that different individual physical characteristics lead to different fatigue levels and recovery (Helland et al., 2020), and this could lead to a greater variability in the study results. More than half participants showed increases on most variables instead of the expected decrease by fatigue induced. The post-activation potential effect might be involved in these findings as this effect is a possible result of muscle contractions (Sale, 2002). Thus, it can also be inferred that probably some athletes did not quite induce this effect on warm-up as others may. The fact that the warm-up was not standardized should be considered in future studies. Even so, our option was based on each athlete's beliefs regarding their state of readiness, suggesting that in further studies, the warm-up should be controlled and also equalized, as a well warm-up structured plan it’s known to affect explosiveness and therefore its outcome (Silva et al., 2018).

Our results can also be interpreted by the one reported by Králová et al. (2019) who found no relationship between actions of the stretch-shortening muscle cycle and 1RM in the Snatch, Clean and Jerk, Back Squat and Deadlift. Interestingly, the authors recommend using the average power output (W) parameter in the Counter Movement Jump as a predictor of current performance level in exercises with an Olympic bar for men and women.

Additionally, we can speculate that some type of exercise may contribute more to a better potentiation of muscle contraction due to the lifted load, the force-velocity curve and also the different levels of induced fatigue (Ebben, 2006; Robbins, 2005; Sale, 2002; Stone et al., 2008; Tillin & Bishop, 2009) and also to different levels of fatigue (Helland et al., 2020). The neuromuscular adaptations induced by weightlifting training strongly depend on the manipulation of the strength training program variables, such as the exercise type and sequence, loading magnitude, volume, interset and intraset rest periods, and lifting velocity (Bird et al., 2005; Kraemer & Ratamess, 2004). A common concern for coaches is deciding how much weight their athletes should lift in a particular exercise as resistance training-induced adaptations are highly dependent on the intensity used (Suchomel et al., 2021).

OW is a competitive sport that requires athletes to lift a maximal amount of weight in the Snatch and C&J. OW has its mainly distinction to sports training in velocity, meaning that other sports train towards developing more speed mostly, maintaining its load (bodyweight only in most cases). However, OW aims to maintain the ideal velocity for each exercise according to its height. Therefore, it is also correlated with lifter's height (Roman, 1974), while manipulating barbell weight could also indicate that OW lifters could be more resistant to velocity loss than other kind of athletes.

In the C&J derivatives, the entire sample only showed significant differences in the C&J exercise itself, and only in ROM and mean power variables while gender groups also showed a significant difference in the C&J exercise. Only on the male group in all variables except peak velocity, clean exercise also was found to have significant differences in ROM variable on the male group while female group have presented no changes to it. The fact that women can perform a greater number of intermittent contractions than men even when the two groups are matched for strength is well known (Hunter et al., 2004), the same principle seem to apply in OW.

Sports, such as OW along with its derivatives, require one single high force or high velocity effort. These movements typically involve a burst of muscular activity of the agonist muscles followed by a phase of relaxation which during the motion continues due to stored momentum. This type of movements are also known as ballistic movements/actions (Wallace & Janz, 2009). In voluntary muscle contractions, the total force output of a muscle depends primarily on the number of motor units and the firing frequency of those motor units in which a higher force output will result in more motor units firing frequency (Wallace & Janz, 2009).

Motor unit recruitment is known to be a critical factor in maximal or ballistic contractions as well as in inducing fatigue. This way (ballistic), the size principle known to be the recruitment threshold of a motor neuron being directly related to the size of its axon, in other words, the larger the axon, the bigger the amount of stimulation required (Henneman, 1957), might not apply as directly as it does in these other types of contractions. In fact, there is some evidence of selective activation of large motor units if the motor task readily demands those motor units (Gillespie et al., 1974).

Ballistic exercises elicit several acute and chronic neurological changes. The standard recruitment of motor units, according to the size principle stays consistent at submaximal exercise intensities but appears to be violated in ballistic movements. It seems that the motor task more than any other variable determines the sequence of activation (Wallace & Janz, 2009). Ultimately, all OW exercises and derivatives have relative high motor recruitment. However, more complex exercises require empirically more units, therefore, are supposed to use more energy, leading to a greater fatigue, however some exercises did not show fatigue, that may be because volume or intensity threshold was not met in that case. In other words, those may be considered "easier" exercises. Recording the bar velocity at which submaximal loads are lifted is a potential method for quantifying the load as a function of the fatigue it causes (García-Ramos et al., 2018; González-Badillo & Sánchez-Medina, 2010). Researchers have reported the general relationship between lifting velocity and the %1RM in different exercises. Nowadays, it seems to be a consensus that the individualized load–velocity relationship allows for a better assessment of athlete fatigue, mainly because the %1PR–velocity relationship is subject specific (González-Badillo et al., 2017; Pestaña-Melero et al., 2018).

4.1. Limitations

Some limitations may be considered, such as: randomization of the sample could only be accomplished to a certain extent since the population to be studied has a small number by itself and the inclusion criteria further narrows this choice; also, OW is a very mental sport which means that those with a better control of the mind may perform better during the personal record setting; additionally, a small sample could also be pointed out as a relative limitation because both male and female were analysed as a group and even more when genders are separated which represented a very small sample size; moreover, specific warm-up wasn't standardized, mainly because lifters have their own warm-up routine, which we choose not to interfere, however it may constitute another unaccountable variable, which could have influenced first and second SPT.

Future research should take the previous information into account and try to measure PRs such as establishing it through determining catch height of each lifter, and setting PR, through the respective SPT height achievement. Moreover, other psychophysiological variables can be considered for a better monitoring such as the rated perceived exertion.

5. Conclusion

This intervention confirmed in fact our hypothesis that when volume and intensity are equated, there are differences between fatigue, induced by OW exercises, exercise typology influences the fatigue induced on athletes.

In Snatch derivatives, peak velocity also showed to be a good variable to quantify fatigue in both genders while all other variables only showed to have changes on females. In addition, females seem more sensible to fatigue in Snatch derivatives. Snatch derivatives are well known for its velocity developing capability, therefore, fatigue may be explained more effectively, by a test that mimics the movement itself such as the SPT.

On C&J exercises, females seem less likely to fatigue than male, therefore they can perform more volume and or intensity. Additionally, ROM, seem to be the variable that we can rely on, C&J exercises are less velocity dependent, this could explain the ROM capability when quantifying fatigue, these ten exercises studied, showed different fatigue levels between them, although we cannot tell the magnitude of this fatigue in this study, we can now plan towards that kind of research, mainly through a higher participant number.

Practical applications

Coaches may plan according to these findings, namely, as to C&J variables, by applying more load to females than to males, and in all other, by using higher relative load on the exercises where fatigue wasn't found. Furthermore, using peak velocity in Snatch and derivatives and ROM in C&J and derivatives seem to show reliable variables for training control.

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Appendix

POLITÉCNICO DE SANTARÉM
ESCOLA SUPERIOR DE DESPORTO DE RIO MAIOR

Laboratório de Investigação em Desporto e Saúde (LIDS)
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CONSENTIMENTO INFORMADO, ESCLARECIDO E LIVRE PARA PARTICIPAÇÃO EM ESTUDOS DE INVESTIGAÇÃO (de acordo com a Declaração de Helsínquia e a Convenção de Oviedo)

Título do estudo: Comparação entre exercícios de halterofilismo e derivados para quantificação do impacto da fadiga.

Enquadramento: O Laboratório de Investigação em Desporto e Saúde (LIDS) da Escola Superior de Desporto de Rio Maior pretende realizar o estudo Comparação entre exercícios de halterofilismo e derivados para quantificação do impacto da fadiga, sobre a coordenação do aluno Mestrando Joaquim Paulo Gonçalves Antunes e do Professor Doutor João Brito e Professor Doutor Rafael Oliveira.

Explicação do estudo: O presente estudo tem o objetivo comparar exercícios de halterofilismo e derivados para quantificação do impacto da fadiga. O estudo será aplicado na Escola Superior de Desporto de Rio Maior, Rio Maior, cuja duração será apenas durante a colheita da informação sob a forma de testes e medidas antropométricas, bem como da realização de um protocolo antes dos referidos testes, 2 vezes por semana. Irá envolver um grupo experimental, serão submetidos a 6 protocolos de teste e 5 protocolos de treino no 1º e também 6 protocolos de teste e 5 protocolos de treino no 2º dia, os testes serão testes de Snatch Pull, entre cada protocolo de exercício, realizados em dois dias distintos por cada participante, bem como a coleta de medidas antropométricas. As avaliações antropométricas serão: Equipamento de composição corporal (Bioimpedância), equipamento de recolha antropométrica (estadiómetro e balança).

Condições: Comparação entre exercícios de halterofilismo e derivados para quantificação do impacto da fadiga, esteve em análise na Comissão de Ética do Instituto Politécnico de Santarém e decorre com meios próprios do Laboratório de Investigação em Desporto e Saúde (LIDS) da Escola Superior de Desporto de Rio Maior. Os participantes na investigação são voluntários, podendo desistir a qualquer momento, e ficam isentos de prejuízos, assistenciais ou outros, caso não queiram participar. De forma a minimizar os riscos de lesão será efetuado um aquecimento e estarão sempre dois ajudantes a acompanhar a execução dos exercícios.

Confidencialidade e anonimato: Em acordo com a Lei n.º 58/2019, de 8 de agosto, que assegura a execução do Regulamento Geral de Proteção de Dados na ordem jurídica portuguesa, os dados que são recolhidos são confidenciais e de uso exclusivo para o presente estudo. De forma a garantir que a confidencialidade dos dados dos participantes está de acordo com as indicações da Comissão Nacional de Proteção de Dados, atesta-se, em qualquer caso, que a identificação dos participantes nunca será tornada pública e sendo assegurado que os contactos serão tratados em ambiente de privacidade e não transmissíveis a terceiros. Após recolha os dados em ficheiro de Excel é atribuído um código a cada participante sendo eliminados todos os elementos, físicos ou em formato digital, de identificação nominal ou contacto dos participantes.

Desde já o nosso muito obrigado pelo vosso contributo fundamental para o desenvolvimento desta investigação.

Pela equipa de trabalho do projeto: Joaquim Paulo Antunes | Aluno de Mestrado do IP Santarém, Escola Superior de Desporto de Rio Maior| joaquimantunes@esdrm.ipsantarem.pt| Telefone: +351 963 289 050; João Brito| Professor coordenador do IP Santarém| jbrito@esdrm.ipsantarem.pt| Telefone: +351 962 418 471| Rafael Oliveira| Professor adjunto do IP Santarém| rafaeloliveira@esdrm.ipsantarem.pt| Telefone: +351 912 664 494

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Declaro ter lido e compreendido este documento, bem como as informações verbais que me foram fornecidas pela/s pessoas que acima assinam. Foi-me garantida a possibilidade de, em qualquer altura, recusar participar neste estudo sem qualquer tipo de consequências. Desta forma, aceito participar neste estudo e permito a utilização dos dados que de forma voluntária forneço, confiando em que apenas serão utilizados para esta investigação e nas garantias de confidencialidade e anonimato que me são dadas pelos investigadores.

Nome: ____

Assinatura: ___________________________________ Data: ____ /_____ /________

SE NÃO FOR O PRÓPRIO A ASSINAR POR IDADE (se o menor tiver discernimento deve também assinar em cima, se consentir)

NOME: ____

BI/CC N.º ___________________________________DATA OU VALIDADE ___. /___ /___.

GRAU DE PARENTESCO OU TIPO DE

REPRESENTAÇÃO: ____________________________________

ASSINATURA: _______________________________________

ESTE DOCUMENTO É COMPOSTO DE 2 PÁGINAS E FEITO EM DUPLICADO: UMA VIA PARA A EQUIPA DE INVESTIGADORES E OUTRA PARA A PESSOA QUE CONSENTE

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Ficha de recolha dos dados

Nome: ____

Data de Nascimento: ____

Peso corporal: ____

Altura: ____

Profissão: ____

Frequência de treino semanal: ____

Duração média de cada treino: ____

Tempo de treino em Halterofilismo: ______________________________________

Desporto praticado anteriormente: _______________________________________

1 RM de snatch: ______________________
1 RM de Clean & Jerk: __________________
1 RM de Back Squat: ___________________
60% snatch: _________________________
60% Clean & Jerk: _____________________
60% Back squat: _______________________

1º teste snatch pull: ___________________
Velocidade média: _____________________
Velocidade Máxima: ____________________
Potência Máxima: ______________________
Máxima amplitude de movimento: ________

2º teste snatch pull: ___________________
Velocidade média: _____________________
Velocidade Máxima: ____________________
Potência Máxima: ______________________
Máxima amplitude de movimento: ________

3º teste snatch pull: ___________________
Velocidade média: _____________________
Velocidade Máxima: ____________________
Potência Máxima: ______________________
Máxima amplitude de movimento: ________

4º teste snatch pull: ___________________
Velocidade média: _____________________

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Velocidade Máxima: ______________________
Potência Máxima: ________________________
Máxima amplitude de movimento: _________

5º teste snatch pull: ______________________
Velocidade média: _______________________
Velocidade Máxima: ______________________
Potência Máxima: ________________________
Máxima amplitude de movimento: _________

6º teste snatch pull: ______________________
Velocidade média: _______________________
Velocidade Máxima: ______________________
Potência Máxima: ________________________
Máxima amplitude de movimento: _________

2ª Avaliação

Data:

1º teste snatch pull: ______________________
Velocidade média: _______________________
Velocidade Máxima: ______________________
Potência Máxima: ________________________
Máxima amplitude de movimento: _________

2º teste snatch pull: ______________________
Velocidade média: _______________________
Velocidade Máxima: ______________________
Potência Máxima: ________________________
Máxima amplitude de movimento: _________

3º teste snatch pull: ______________________
Velocidade média: _______________________
Velocidade Máxima: ______________________
Potência Máxima: ________________________
Máxima amplitude de movimento: _________

4º teste snatch pull: ______________________
Velocidade média: _______________________
Velocidade Máxima: ______________________
Potência Máxima: ________________________
Máxima amplitude de movimento: _________

5º teste snatch pull: ______________________
Velocidade média: _______________________
Velocidade Máxima: ______________________
Potência Máxima: ________________________

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Máxima amplitude de movimento: __________

6º teste snatch pull: ______________________
Velocidade média: ______________________
Velocidade Máxima: ______________________
Potência Máxima: ______________________
Máxima amplitude de movimento: __________

7º teste snatch pull: ______________________
Velocidade média: ______________________
Velocidade Máxima: ______________________
Potência Máxima: ______________________
Máxima amplitude de movimento: __________

POLITÉCNICO DE SANTARÉM

DECLARAÇÃO

COMISSÃO DE ÉTICA DA UNIDADE DE INVESTIGAÇÃO DO IPSANTARÉM

EMISSÃO DE PARECER 07A-2021ESDRM

Identificação do Investigador | João Paulo Moreira de Brito (ESDRM) e Joaquim Paulo Gonçalves Antunes (ESDRM)

Identificação do Projeto | *Comparison between Olympic weightlifting exercises and derivatives for fatigue impact quantification*

Considerando que:

- É um trabalho académico de investigação
- Apresenta fundamentação teórica, objetivos e a metodologia (incluindo procedimentos e instrumentos de recolha de dados) e princípios éticos a adotar.
- É apresentado o consentimento informado, assegurando o anonimato sendo eliminados todos os elementos, físicos ou em formato digital, de identificação nominal ou contacto dos participantes.

Somos de parecer positivo que este projeto de natureza académica cumpre os requisitos éticos inerente ao respeito pela autonomia dos participantes, para o período consignado no cronograma e a clarificação do acesso à investigação.

Santarém, 29 de outubro de 2021

Pedro Oliveira

(Coordenador)

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healthcare

MDPI

Original Research

Comparison between Olympic Weightlifting Lifts and Derivatives for Fatigue Impact Quantification

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Abstract: Load management is an extremely important subject in fatigue control and adaptation process in almost all sports. In Olympic Weightlifting (OW), two of the load variables are intensity and volume. However, it is not known if all exercises produce fatigue of the same magnitude. Thus, this study aimed to compare the amount of fatigue induced by two of the most used weightlifting exercises, namely, the Clean & Jerk and the Snatch with their derivative exercises. We resorted to an experimental quantitative design in which fatigue was induced in adult individuals with weightlifting experience of at least two years, through the execution of a set of 10 of the most used lifts and derivatives in OW (Snatch, Snatch Pull, Muscle Snatch, Power Snatch, and Back Squat; Clean & Jerk, Power Clean, Clean, High Hang Clean, and Hang Power Clean). Intensity and volume between exercises were equalized (four sets of three repetitions), after which one Snatch Pull test was performed where changes in velocity, range of motion and mean power were assessed as fatigue measures. Nine women and 12 men have participated in the study (age, 29.67±5.74years and 28.17±5.06years, respectively). The main results showed higher peak velocity values for Snatch Pull test when compared with Power Snatch (p=0.008; ES=0.638), Snatch (p<0.001; ES=0.998), Snatch Pull (p<0.001, ES=0.906), and Back Squat (p<0.001; ES=0.906) while the different between Snatch Pull test and the derivatives of Clean & Jerk were almost inexistent. It is concluded that there were differences in the induction of fatigue between most of the exercises analysed and therefore, coaches and athletes could improve planning the training sessions accounting for the fatigue induced by each lift.

Keywords: Olympic exercises; Clean & Jerk; Snatch; Squat; Weightlifting derivatives; Power clean; Power.

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1. Introduction

Olympic Weightlifting (OW) is a dynamic strength and power sport in which two complex lifts/exercises are performed in competition: the Snatch and the Clean and Jerk (C&J). During these lifts, weightlifters have achieved some of the highest peak power outputs reported in the literature [1,2].

The Snatch requires the weighted barbell to be lifted from the floor (usually using a wide grip) to an overhead position in one continuous movement [3]. The C&J is divided in two main phases in which the first requires the barbell to be raised from the floor (using a shoulder width grip) to the front of the shoulders in one continuous movement [4] and the second phase consists in the jerk which is the barbell is propelled from the shoulders to arm's length overhead by the forces produced primarily by the hips and thighs [5].

Considering that weightlifting is used in strength development in most sports, some questions arise: how to train weightlifting efficiently and how it reflects in the performance at other sports that use weightlifting exercises and their derivatives (e.g., Hang Clean, Hang Snatch, Power Clean, Power Snatch, and High pull). The answer to these questions may require enhancing testing and training methods of weightlifting rough the combination of the main exercises and their derivatives [6]. Weightlifting exercises and their derivatives exercises have become a popular training modality to improve high strength and power expressions throughout the whole force-velocity spectrum during movement, across a range of sports [7-13]

Monitoring, planning and periodizing training loads are critical factors when it comes to the athlete's development and progression. There has been an attempt by researchers to increasingly identify the variables of training, to control them. In fact, in the past, even the successful Bulgarian methodology tried to reduce some variables, by the reduction of the variety of exercises used [14]. Therefore, there are still some factors that remain unknown. In OW training load variables such as volume (number of repetitions multiplied by the number of sets) are often manipulated. On the other hand, intensity which is expressed relatively to the maximal load (kilograms) obtained in the main exercises. Another variable which is also commonly used is the total load, which is characterized by the number of sets multiplied by the number of repetitions multiplied by the kilograms lifted, also known as tonnage [15].

The magnitude of force production and the capacity to perform a given amount of work as rapidly as possible are often suggested as primary underpinning qualities of sport skills. Thus, developing strength, power and speed capabilities are frequently primary aims of many athletic development programs [16]. Despite the variables that define the load have been described namely in terms of intensity by volume [17], there are several parallel factors that may still be associated with this quantification, namely the type and exercise selection [18]. More recently other algorithms for grouping and selection of exercises have been proposed, in some cases based on technical efficiency [19]. Factors such as the number and type of muscle fibers involved, either because of the complexity of the movement, or because of the amount of force developed in a given unit of time, can vary in each exercise [11], thus creating an unknown additional fatigue.

Several researchers [20-22] have highlighted strong relationships between load and movement velocity fatigue, with the assessment of strength qualities being load-velocity specific. Therefore, it is particularly important to know the fatigue induced by the different OW derivatives when programming the training load. It is essential to know which exercises induce greater fatigue and its magnitude. High-power outputs and rate of force development expressed in weightlifting movements and derivatives [2], in conjunction with the motor control and coordination demands on the trunk and lower body muscles to stabilize and transmit forces [23], can effectively impact and compromise various aspects of an athlete's load-velocity profile [16].

This is a topic that has been scarcely addressed in the literature, thereby lacking results that may improve coaching, both in terms of exercise selection, and of their distribution along the microcycles, mesocycles and macrocycles. Several attempts have already been made to try to organize the various exercises into clusters-approach [15]. However, exercise-induced fatigue was never deepened.

Thus, the aim of the present study was to compare the fatigue prompted by the Clean & Jerk, the Snatch, and their derivative exercises (Snatch, Snatch Pull, Muscle Snatch, Power Snatch, and Back Squat; Clean & Jerk, Power Clean, Clean, High Hang Clean, Hang Power Clean) for the total, male and female participants, respectively. It was hypothesized that when volume and intensity are equated, there are differences in fatigue induced by performing the different OW derivative exercises.

2. Materials and Methods

2.1. Design

This is a cross-sectional study conducted in two separated days, apart by a minimum of three days and a maximum of five days. All procedures were recorded for future consult at protocols.io website (DOI: dx.doi.org/10.17504/protocols.io.n92ldzxq8v5b/v1), and the sample represents more than 10% of the OW Portuguese population [24].

2.2. Participants

An a priori power analysis using G*Power (Statistical Power Analyses software for Windows - RRID: SCR_013726) was completed [25]. A sample size calculation was made for the difference between two dependent means (Paired sample T-test), an effect size of 0.8, an alpha of ≤ 0.05 and beta of 0.95. It was determined that at least 19 participants were needed. Twenty-one Caucasian participants, 12 males and 9 females volunteered to participated in the study.

The inclusion criteria was: to be aged between 18 and 40 years; having more than 2 years of OW training and; competing at national level and having between 61 and 96 kgs bodyweight for the male group, and between 49 and 71 kgs for the female group. The characteristics of the participants are presented in table 1.

Table 1. Participants' characteristics

	Age (years)	**Height** (cm)	**Weight** (kg)	**BF** (%)	**FFM** (kg)
Female	29.7±5.7	158.8±6.7	60.8±7,3	17.8±7.6	48.9±7.7
Male	28.1±5.0	174.5±6.0	79.5±5.3	17.0±5.1	65.9±5.0
Total	28.8±5.3	167.8±10.1	71.5±11.2	17.3±6.2	58.6±10.6

BF, body fat; FFM, fat free mass.

Data collection took place at each participants usual training gym. Prior to their participation, each participant was familiarized with all procedures. Moreover, they read and signed a written informed consent form, in accordance with the university's institutional review board, before data collection. This study was designed according to the recommendations of the World Medical Association's Declaration of Helsinki of 1975, as revised in 2013, for human studies and approved by the Institutional Ethics Committee (approval number: 07A-2021ESDRM).

2.3. Exercise selection

The exercise selection was based on its ability to enhance the force–velocity profile of athletes [12], as well as the exercise frequency applied by OW coaches [26]. The selected exercises were the Snatch and its derivatives exercises (Muscle Snatch; Power Snatch; Snatch; Snatch Pull; Back Squat) and the Clean & Jerk (C&J) and its derivative exercises (Power Clean; C&J; Clean; High Hang Clean; Hang Power Clean).

2.4. Performance assessment

Usually, the isometric mid-thigh pull test (IMTP) is a reliable and popular way to test maximal strength in adult athletes. Administering a partial movement test is a safer and more time-efficient method than traditional 1RM testing. The IMTP produce itself relatively little fatigue and has a low potential for injury [27], but it proved to be less effective in predicting the competitive performance of OW than other tests [28]. When considering the concept of neuromuscular fatigue, it is important to note that isometric versus dynamic measurements do not provide the same results. Additionally, bar range of motion (ROM) also plays an important role in OW, and it seems to be an important factor when assessing fatigue [29]. Therefore, we opted by the Snatch Pull Test (SPT) as a reference measure, which has been correlated with the Personal Record (PR) of the Snatch exercise (r=0.99) [30]. In all OW derivatives, mean velocity, peak velocity, mean power and ROM were measured using the Isoinertial Dynamometer Vitruve (Vitruve encoder; Madrid, Spain) (previously Speed4Lifts) [31]. Moreover, this type of tests can regularly be applied during weightlifting training as a valid alternative to the personal record Snatch test to assess individualized progression in weightlifting performance over time [30].

Since all these lifts have a correlation intensity with each other, and Muscle Snatch is referenced as 60 to 65% of the Snatch PR, the intensity load of 60% was chosen. Therefore, setting it as baseline intensity, the volume chosen (4 sets of 3 repetitions) was the amount of load that is usually performed by lifters within the intensity already settled [26].

2.5. Procedures

On the first day of data collection, participants started early in the morning the anthropometric assessment, namely, height, weight, and body composition by bioimpedance analysis.

2.5.1 Anthropometric and Body Composition Assessment

The anthropometric and body composition measures were obtained with the subjects dressed in light clothing without shoes following previous recommendations [32] through a stadiometer with an incorporated scale (Seca 220, Hamburg, Germany) according to standardized procedures [33]. The body composition data were obtained with bioelectrical impedance analysis through Inbody S10 (model JMW140, Biospace Co, Ltd., Seoul, Korea), according to manufacturer's guidelines [34,35]. Eight electrodes were placed on eight tactile points (thumbs, middle fingers and ankles of both hands and feet, respectively) to perform the multi-segmental frequency analysis. The parameters collected were body fat mass (BFM) and fat-free mass (FFM).

The measurements were carried out in the morning, in a room with an ambient temperature and relative humidity of 22–23°C and 50–60%, respectively, after a minimum of 8 h of fasting and after the bladder was emptied following previous suggestions [32,36]. The participants adopted a supine position with their arms and legs abducted at a 45° angle, the skin was cleaned with ethyl alcohol and hydrophilic cotton at the eight electrode placement sites. After a 10 min rest in a room without noise, eight electrodes were placed on the cleaned surfaces and the measurements were performed.

Before data collection, participants did not exercise or ingest caffeine or alcohol during the 12 h prior to the assessment. In addition, participants removed all objects that could interfere with the bioelectrical impedance assessment.

Female participants were only assessed if they were in the luteal phase of ovulatory menstrual cycles. Otherwise, they waited until they were in the luteal phase. All the assessments were performed by the same evaluator to minimize possible measurement errors [37].

2.5.2 Test Protocol

After anthropometric and body composition assessment, an explanation and familiarization with the protocol was provided. A 10-minute warm-up including mobility exercises, OW repetitions and jumps were carried out before the beginning of each training session. To minimize the risk of injury there were always two assistants to monitor exercise execution.

Participants started their personal warm-up exercise/specific for training session up to 60% of the Snatch 1RM, followed by two 50%, one 70% and one at 100% of Snatch 1RM, SPT attempts separated by 1 minute recovery [38]. Before each SPT, verbal feedback cues were given by coaches in a standardized form, namely "Pull hard and fast."

On the first test day, Snatch and Derivatives protocol took place. After the warm-up, the baseline SPT evaluation occurred (figure 1), making 1RM of Snatch personal record after which data was collected. Then participants rested 1 minute followed by the Muscle Snatch protocol of 4 sets of 3 repetitions, at 60% of the Snatch 1RM (1 minute rest between sets). After the protocol, participants then took 1 minute rest before the post Muscle Snatch SPT evaluation (1RM).

Followed by the Power Snatch protocol of 4 sets of 3 repetitions, at 60% of the Snatch 1RM (1 minute rest between sets). After the protocol, participants then took 1 minute rest before the post Power Snatch SPT evaluation, also one repetition at 100% Snatch 1RM after which data was collected, participants would then rest 1 minute.

The same protocol was used for the Snatch, Snatch Pull and Back Squat. On the second test day, three days after the tests were performed in the Snatch derivatives exercises, the C&J and derivative exercises protocol was performed.

The same protocol used in the Snatch derivatives was used for all C&J derivatives within the following order, Power Clean, C&J, Clean, High Hang Clean and Hang Power Clean. In this protocol 60% of the C&J 1RM was used.

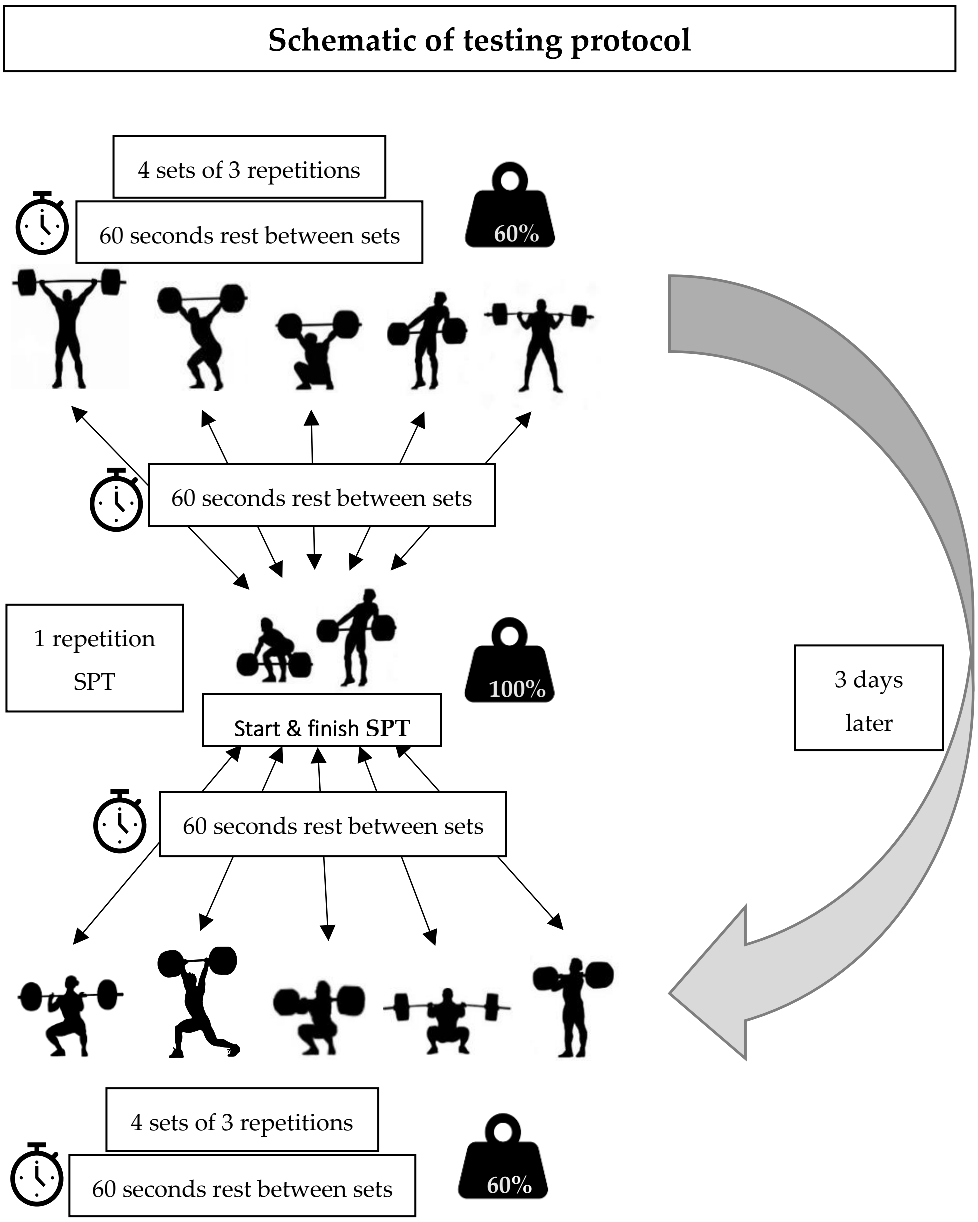

Figure 1. Testing protocol schematic.

2.6. Statistical Analysis

All statistical analysis were performed using IBM SPSS for Windows (IBM Corp. Released 2020., Version 28.0. Armonk, NY, USA). Data was described as means ± standard deviation (SD), standard error of the mean (SEM) and mean difference (MD) with 95% of confidence interval (CI). Shapiro–Wilk test is used for testing normality. Differences between exercise fatigue were examined using a paired-samples t-test (velocity, range of motion, and mean power, within each exercise monitored, using the isoinertial dynamometer). An a-priori level of significance was set at $p < 0.05$ and a percentage change with 95% CI. The effect size (ES) was calculated to determine the magnitude of the effects through the Cohen's d according to the following thresholds: large $d > 0.8$, moderate d between 0.8 and 0.5, small d between 0.49 and 0.20, trivial $d < 0.2$ [39].

3. Results

3.1. Snatch derivative protocols

Analysing the mean power for the entire sample (n=21), it was found that after the Muscle Snatch protocol, there were no significant differences while post- Power Snatch, Snatch, Snatch Pull and Back Squat showed a significant difference (Table 2). However, when considering the gender groups analysis separately, female group (n=9) reveals no difference after the Muscle Snatch and Power Snatch protocol whereas Snatch, Snatch Pull and Back Squat manifested a significant difference. The male group (n =12) did not reveal significant differences in mean power for any exercise.

Mean velocity evidenced a significant difference in the Snatch and Back Squat (Table 2) for the total sample. When gender groups were analysed, female group showed difference after the Snatch, Snatch Pull and Back Squat (Table 3). No differences were found in the male group.

Peak velocity did not show a significant difference for Muscle Snatch while the remaining derivatives showed significant differences (Table 2). Female group did not report differences after the Muscle Snatch and Power Snatch protocol (Table 3). No differences were found for the male group in Muscle Snatch and Back Squat.

For the total sample, only the Muscle Snatch protocol, revealed differences in range of motion (Table 2). In the genders analysis (Table 3), female group revealed that after the Muscle Snatch protocol, the Snatch, Snatch Pull and Back Squat exercises presented a significant difference while in the male group, only Snatch Pull showed differences.

Table 2. Baseline and post values of Snatch Pull Test on the Snatch derivatives (♀♂= 21).

Parameter	**Weightlifting derivative**		**Mean±SD**	**SEM**	**MD (95%CI)**	***p* (ES)**
			Baseline			
		SPT	106.49±7.49	1.64		
			Post			
ROM (cm)	Pair 1	Muscle Snatch	107.33±7.75	1.69	-0.85 (-2.65; 0.95)	0.338 (-0.214)
	Pair 2	Power Snatch	105.15±7.93	1.73	1.34 (-0.36; 3.04)	0.116 (0.358)
	Pair 3	Snatch	104.19±7.85	1.71	2.30 (0.87; 3.73)	0.003* (0.731)
	Pair 4	Snatch Pull	102.82±8.63	1.88	3.67 (1.97; 5.36)	<0.001** (0.986)
	Pair 5	Back Squat	103.97±9.41	2.05	2.52 (0.42; 4.62)	0.021* (0.547)

			Baseline			
		SPT	706.55±187.58	40.93		
			Post			
Mean Power (w)	Pair 1	Muscle Snatch	701.93±189.80	41.42	4.61 (-18.41; 27.64)	0.680 (0.091)
	Pair 2	Power Snatch	681.19±181.14	39.53	25.36 (0.93; 49.79)	0.043* (0.472)
	Pair 3	Snatch	677.11±183.49	40.04	29.44 (0.32; 58.55)	0.048* (0.460)
	Pair 4	Snatch Pull	664.41±180.76	39.44	42.14 (15.84; 68.44)	0.003* (0.729)
	Pair 5	Back Squat	671.32±190.58	41.59	35.22 (10.03; 60.42)	0.009* (0.636)
			Baseline			
		SPT	1.81±0.17	0.04		
			Post			
Peak Velocity (m/s)	Pair 1	Muscle Snatch	1.78±0.18	0.04	0.04 (-0.01; 0.09)	0.125 (0.350)
	Pair 2	Power Snatch	1.76±0.19	0.04	0.06 (0.02; 0.10)	0.008* (0.638)
	Pair 3	Snatch	1.73±0.17	0.04	0.08 (0.05; 0.12)	<0.001** (0.998)
	Pair 4	Snatch Pull	1.72±0.15	0.03	0.09 (0.05; 0.14)	<0.001** (0.906)
	Pair 5	Back Squat	1.73±0.18	0.04	0.08 (0.04; 0.13)	<0.001** (0.906)
			Baseline			
		SPT	0.94±0.13	0.03		
			Post			
Mean Velocity (m/s)	Pair 1	Muscle Snatch	0.93±0.12	0.03	0.01 (-0.02; 0.04)	0.508 (0.147)
	Pair 2	Power Snatch	0.91±0.13	0.03	0.03 (0.00; 0.06)	0.050 (0.455)
	Pair 3	Snatch	0.90±0.13	0.03	0.04 (0.00; 0.07)	0.030* (0.509)
	Pair 4	Snatch Pull	0.92±0.15	0.03	0.02 (-0.06; 0.10)	0.604 (0.115)
	Pair 5	Back Squat	0.89±0.13	0.03	0.05 (0.02; 0.08)	0.003* (0.727)

SPT, snatch pull test; ROM, range of motion; *, p<0.05; **, p<0.001; SD, standard deviation; SEM, standard error of the mean; MD, mean difference; CI, confidence intervals; ES, effect size.

In the assessment of the Snatch variables, it was verified that ROM, post Snatch Pull protocol, as well as peak velocity, post Snatch, Snatch Pull and Back Squat, showed differences when total sample was analysed. 246 247 248

Table 3. Baseline and post values of Snatch Pull Test on the Snatch derivatives by gender (♀=9; ♂= 12). 249

Parameter		**Weightlifting derivative**		**Mean±SD**	**SEM**	**MD (95%CI)**	***p* (ES)**
				Baseline			
			SPT	105.22±8.25	2.75		
				post			
ROM (cm)	**Female**	Pair 1	Muscle Snatch	105.16±9.00	3.00	0.07 (-2.18; 2.32)	0.947 (0.023)
		Pair 2	Power Snatch	104.58±9.29	3.10	0.64 (-1.95; 3.23)	0.585 (0.189)
		Pair 3	Snatch	102.04±9.17	3.06	3.18 (1.17; 5.18)	0.006* (1.218)
		Pair 4	Snatch Pull	100.40±10.44	3.48	4.82 (2.73; 6.91)	0.001* (1.776)

		Pair 5	Back Squat	100.03±10.91	3.64	5.19 (2.48; 7.90)	0.002* (1.474)
	Male			Baseline			
			SPT	107.43±7.10	2.05		
				post			
		Pair 1	Muscle Snatch	108.97±6.59	1.90	-1.53 (-4.45; 1.38)	0.272 (-0.334)
		Pair 2	Power Snatch	105.57±7.16	2.10	1.87 (-0.71; 4.44)	0.139 (0.460)
		Pair 3	Snatch	105.79±6.66	1.92	1.64 (-0.55; 3.84)	0.128 (0.475)
		Pair 4	Snatch Pull	104.63±6.91	2.00	2.80 (0.11; 5.49)	0.042* (0.663)
		Pair 5	Back Squat	106.91±7.23	2.09	0.52 (-2.28; 3.32)	0.692 (0.117)
Mean Power (w)	**Female**			Baseline			
			SPT	557.79±128.94	42.98		
				post			
		Pair 1	Muscle Snatch	540.79±113.25	37.75	17.00 (-0.81; 34.81)	0.059 (0.734)
		Pair 2	Power Snatch	536.32±121.34	40.45	21.47 (-4.20; 47.13)	0.090 (0.643)
		Pair 3	Snatch	521.19±113.48	37.83	36.60 (13.67; 59.53)	0.006* (1.227)
		Pair 4	Snatch Pull	518.99±121.16	40.39	38.80 (19.07; 58.53	0.002* (1.512)
		Pair 5	Back Squat	518.82±128.90	42.97	38.97 (21.13; 56.81)	0.001* (1.679)
	Male			Baseline			
			SPT	818,12±142.13	41.03		
				post			
		Pair 1	Muscle Snatch	822.79±137.79	39.78	-4.68 (-45.08; 35.73)	0.804 (-0.074)
		Pair 2	Power Snatch	789.84±137.47	39.68	28.28 (-13.89; 70.44)	0.168 (0.426)
		Pair 3	Snatch	794.05±130.53	37.68	24.07 (-28.01; 76.14)	0.331 (0.294)
		Pair 4	Snatch Pull	773.47±135.84	39.21	44.65 (-2.79; 92.08)	0.063 (0.598)
		Pair 5	Back Squat	785.70±143.73	41.49	32.42 (-13.22; 78.05)	0.146 (0.451)
Peak Velocity (m/s)	**Female**			Baseline			
			SPT	1.88±0.17	0.06		
				post			
		Pair 1	Muscle Snatch	1.84±0.15	0.05	0.04 (-0.01; 0.09)	0.102 (0.615)
		Pair 2	Power Snatch	1.86±0.16	0.05	0.02 (-0.04; 0.08)	0.422 (0.282)
		Pair 3	Snatch	1.78±0.15	0.05	0.10 (0.05; 0.16)	0.002* (1.469)
		Pair 4	Snatch Pull	1.76±0.17	0.06	0.12 (0.05; 0.20)	0.005* (1.258)
		Pair 5	Back Squat	1.74±0.21	0.07	0.14 (0.09; 0.20)	<0.001* (2.058)
	Male			Baseline			
			SPT	1.76±0.16	0.05		
				post			
		Pair 1	Muscle Snatch	1.73±0.19	0.05	0.04 (-0.05; 0.12)	0.378 (0.265)
		Pair 2	Power Snatch	1.68±0.18	0.05	0.09 (0.03; 0.14)	0.009* (0.910)
		Pair 3	Snatch	1.69±0.17	0.05	0.07 (0.01; 0.13)	0.025* (0.745)

		Pair 4	Snatch Pull	1.69±0.14	0.04	0.07 (0.00; 0.14)	0.039* (0.675)
		Pair 5	Back Squat	1.73±0.17	0.05	0.04 (-0.01; 0.09)	0.134 (0.467)
Mean Velocity (m/s)	**Female**			Baseline			
		SPT		0.99±0.14	0.05		
				post			
		Pair 1	Muscle Snatch	0.97±0.13	0.04	0.03 (-0.00; 0.06)	0.063 (0.719)
		Pair 2	Power Snatch	0.97±0.14	0.05	0.02 (-0.01; 0.06)	0.144 (0.540)
		Pair 3	Snatch	0.93±0.14	0.05	0.06 (0.02; 0.10)	0.006* (1.228)
		Pair 4	Snatch Pull	0.92±0.11	0.04	0.07 (0.03; 0.11)	0.003* (1.372)
		Pair 5	Back Squat	0.92±0.14	0.05	0.07 (0.04; 0.10)	0.001* (1.660)
	Male			Baseline			
		SPT		0.89±0.12	0.03		
				post			
		Pair 1	Muscle Snatch	0.90±0.10	0.03	-0.01 (-0.05; 0.04)	0.806 (-0.073)
		Pair 2	Power Snatch	0.86±0.11	0.03	0.03 (-0.02; 0.08)	0.174 (0.419)
		Pair 3	Snatch	0.87±0.12	0.03	0.02 (-0.04; 0.08)	0.412 (0.246)
		Pair 4	Snatch Pull	0.91±0.18	0.05	-0.02 (-0.17; 0.13)	0.800 (-0.075)
		Pair 5	Back Squat	0.86±0.13	0.04	0.03 (-0.02; 0.09)	0.174 (0.420)

SPT, snatch pull test; ROM, range of motion; *, p<0.05; SD, standard deviation; SEM, standard error of the mean; MD, mean difference; CI, confidence intervals; ES, effect size.

3.2. Clean and Jerk derivative protocols

Only in the C&J mean power and mean velocity, differences were found when considering all sample (Table 4) and when considering the male group (Table 5).

Table 4. Baseline and post values of Snatch Pull Test on the Clean & Jerk derivatives (♀♂= 21).

Parameter		**Weightlifting derivative**	**Mean±SD**	**SEM**	**MD (95%CI)**	***p* (ES)**
ROM (cm)			Baseline			
		SPT	106.01±8.00	1.75		
			post			
	Pair 1	Power Clean	105.77±7.91	1.73	0.24 (-0.91; 1.39)	0.671 (0.094)
	Pair 2	Clean & Jerk	103.91±8.88	1.94	2.10 (0.46; 3.73)	0.015* (0.582)
	Pair 3	Clean	104.67±8.77	1.91	1.34 (-0.27; 2.96)	0.098 (0.378)
	Pair 4	High Hang Clean	105.03±8.98	1.96	0.98 (-0.43; 2.38)	0.164 (0.316)
	Pair 5	Hang Power Clean	104.92±8.41	1.83	1.09 (-0.81; 2.99)	0.245 (0.261)
Mean Power (w)			Baseline			
		SPT	699.81±176.31	38.47		
			post			
	Pair 1	Power Clean	700.49±183.15	39.97	-0.68 (-16.10; 14.74)	0.928 (-0.020)

	Pair 2	Clean & Jerk	675.26±170.43	37.19	24.55 (1.65; 47.44)	0.037* (0.488)
	Pair 3	Clean	679.59±180.17	39.32	20.22 (-5.70; 46.14)	0.119 (0.355)
	Pair 4	High Hang Clean	690.40±178.72	39.00	9.41 (-16.66; 35.48)	0.460 (0.164)
	Pair 5	Hang Power Clean	687.63±176.81	38.58	12.18 (-13.46; 37.82)	0.334 (0.216)
Peak Velocity (m/s)			Baseline			
		SPT	1.75±0.16	0.03		
			post			
	Pair 1	Power Clean	1.75±0.17	0.04	-0.01 (-0.05; 0.04)	0.809 (-0.054)
	Pair 2	Clean & Jerk	1.74±0.18	0.04	0.01 (-0.02; 0.04)	0.456 (0.166)
	Pair 3	Clean	1.74±0.18	0.04	0.01 (-0.03; 0.04)	0.712 (0.082)
	Pair 4	High Hang Clean	1.74±0.16	0.03	0.01 (-0.02; 0.04)	0.511 (0.146)
	Pair 5	Hang Power Clean	1.75±0.15	0.03	0.00 (-0.03; 0.04)	0.819 (0.051)
Mean Velocity (m/s)			Baseline			
		SPT	0.93±0.11	0.02		
			post			
	Pair 1	Power Clean	0.93±0.11	0.02	0.00 (-0.02; 0.02)	0.846 (0.043)
	Pair 2	Clean & Jerk	0.90±0.12	0.03	0.03 (0.00; 0.06)	0.050 (0.478)
	Pair 3	Clean	0.90±0.11	0.02	0.03 (-0.00; 0.06)	0.071 (0.415)
	Pair 4	High Hang Clean	0.91±0.11	0.03	0.01 (-0.02; 0.04)	0.358 (0.205)
	Pair 5	Hang Power Clean	0.91±0.11	0.02	0.02 (-0.01; 0.05)	0.227 (0.272)

SPT, snatch pull test; ROM, range of motion; *, p<0.05; SD, standard deviation; SEM, standard error of the mean; MD, mean difference; CI, confidence intervals; ES, effect size

Regarding peak velocity, no differences were found in all exercises and in both groups. For total sample, ROM only showed a significant difference in the C&J (Table 4). In the group analysis, only the male group showed differences in the C&J and Clean (Table 5).

Table 5. Baseline and post values of Snatch Pull Test on the Clean & Jerk derivatives (♀= 9; ♂= 12).

Parameter			**Weightlifting derivative**	**Mean±SD**	**SEM**	**MD (95%CI)**	***p* (ES)**
ROM (cm)	**Female**			Baseline			
			SPT	102.14±6.68	2.23		
				post			
		Pair 1	Power Clean	102.77±7.98	2.66	-0.62 (-2.78; 1.54)	0.525 (-0.222)
		Pair 2	Clean & Jerk	101.93±8.16	2.72	0.21 (-2.16; 2.58)	0.843 (0.068)
		Pair 3	Clean	102.18±8.70	2.90	-0.03 (-3.03; 2.96)	0.980 (-0.009)
		Pair 4	High Hang Clean	102.03±8.87	2.96	0.11 (-2.42; 2.64)	0.922 (0.034)
		Pair 5	Hang Power Clean	101.47±7.26	2.42	0.68 (-1.42; 2.77)	0.477 (0.248)

				Baseline			
			SPT	108.91±7.91	2.28		
				post			
	Male	Pair 1	Power Clean	108.03±7.38	2.13	0.88 (-0.51; 2.28)	0.192 (0.401)
		Pair 2	Clean & Jerk	105.40±9.44	2.73	3.51 (1.35; 5.67)	0.004* (1.033)
		Pair 3	Clean	106.53±8.72	2.52	2.38 (0.46; 4.29)	0.020* (0.786)
		Pair 4	High Hang Clean	107.28±8.74	2.52	1.63 (-0.22; 3.47)	0.079 (0.559)
		Pair 5	Hang Power Clean	107.51±8.55	2.47	1.40 (-1.84; 4.64)	0.362 (0.275)
Mean Power (w)				Baseline			
			SPT	536.97±100.78	33.59		
				post			
	Female	Pair 1	Power Clean	539.52±125.88	41.96	-2.56 (-27.66; 22.55)	0.820 (-0.078)
		Pair 2	Clean & Jerk	539.18±132.05	44.02	-2.21 (-33.10; 28.63)	0.873 (-0.055)
		Pair 3	Clean	533.22±130.91	43.64	3.74 (-26.22; 33.70)	0.781 (0.096)
		Pair 4	High Hang Clean	542.37±125.61	41.87	-5.40 (-27.63; 16.83)	0.591 (-0.187)
		Pair 5	Hang Power Clean	528.48±120.75	40.30	8.49 (-15.44; 32.41)	0.437 (0.273)
				Baseline			
			SPT	821.94±105.66	30.50		
				post			
	Male	Pair 1	Power Clean	821.21±111.21	32.10	0.73 (-22.23; 23.69)	0.945 (0.020)
		Pair 2	Clean & Jerk	777.33±116.69	33.68	44.62 (13.47; 75.76)	0.009* (0.910)
		Pair 3	Clean	789.37±126.03	36.38	32.58 (-9.58; 74.73)	0.117 (0.491)
		Pair 4	High Hang Clean	801.42±123.38	35.62	20.53(-24.59; 65.64)	0.338 (0.289)
		Pair 5	Hang Power Clean	806.99±99.85	28.82	14.95 (-30.17; 60.07)	0.481 (0.211)
Peak Velocity (m/s)				Baseline			
			SPT	1.80±0.13	0.04		
				post			
	Female	Pair 1	Power Clean	1.80±0.15	0.05	-0.01 (-0.10; 0.05)	0.795 (-0.090)
		Pair 2	Clean & Jerk	1.82±0.12	0.04	-0.02 (-0.06; 0.02)	0.231 (-0.081)
		Pair 3	Clean	1.81±0.15	0.05	-0.01 (-0.07; 0.05)	0.725 (-0.121)
		Pair 4	High Hang Clean	1.79±0.15	0.05	0.01 (-0.06; 0.07)	0.849 (0.066)
		Pair 5	Hang Power Clean	1.77±0.16	0.05	0.03 (-0.04; 0.10)	0.377 (0.312)
				Baseline			
			SPT	1.72±0.17	0.05		
				post			
	Male	Pair 1	Power Clean	1.72±0.18	0.05	-0.00 (-0.08; 0.07)	0.903 (-0.036)
		Pair 2	Clean & Jerk	1.68±0.20	0.06	0.04 (-0.01; 0.08)	0.089 (0.539)
		Pair 3	Clean	1.70±0.19	0.05	0.02 (-0.03; 0.07)	0.437 (0.233)
		Pair 4	High Hang Clean	1.70±0.16	0.05	0.01 (-0.03; 0.05)	0.459 (0.222)

		Pair 5	Hang Power Clean	1.73±0.15	0.04	-0.02 (-0.06; 0.03)	0.492 (-0.205)
Mean Velocity (m/s)	Female			Baseline			
		SPT		0.96±0.12	0.04		
				post			
		Pair 1	Power Clean	0.96±0.12	0.04	0.00 (-0.04; 0.04)	0.901 (0.043)
		Pair 2	Clean & Jerk	0.96±0.12	0.04	0.01 (-0.04; 0.06)	0.773 (0.099)
		Pair 3	Clean	0.95±0.11	0.04	0.02 (-0.04; 0.07)	0.493 (0.239)
		Pair 4	High Hang Clean	0.96±0.11	0.04	-0.00 (-0.04; 0.04)	0.947 (-0.023)
		Pair 5	Hang Power Clean	0.94±0.11	0.04	0.02 (-0.03; 0.07)	0.322 (0.352)
	Male			Baseline			
		SPT		0.90±0.10	0.03		
				post			
		Pair 1	Power Clean	0.90±0.10	0.03	0.00 (-0.02; 0.03)	0.890 (0.041)
		Pair 2	Clean & Jerk	0.86±0.10	0.03	0.05 (0.01; 0.08)	0.011* (0.876)
		Pair 3	Clean	0.86±0.10	0.03	0.04 (-0.01; 0.08)	0.091 (0.535)
		Pair 4	High Hang Clean	0.88±0.11	0.03	0.02 (-0.02; 0.07)	0.282 (0.326)
		Pair 5	Hang Power Clean	0.89±0.11	0.03	0.01 (-0.03; 0.06)	0.489 (0.207)

SPT, snatch pull test; ROM, range of motion; *, p<0.05; SD, standard deviation; SEM, standard error of the mean; MD, mean difference; CI, confidence intervals; ES, effect size.

4. Discussion

The aim of the present study was to compare the amount of fatigue caused by the Clean & Jerk, the Snatch and their derivative exercises (Snatch, Snatch Pull, Muscle Snatch, Power Snatch, and Back Squat; Clean & Jerk, Power Clean, Clean, High Hang Clean, Hang Power Clean). The majority of these exercises are also used in OW as well as in general strength and conditioning training programs for various sports [9,40-43]. It was hypothesized that when volume and intensity are equated, there are differences between fatigue, induced by different OW exercises.

The main results showed that for the total sample, significant differences were found in the Snatch pull, Snatch and Back Squat ROM and on C&J ROM. Regarding the mean power, significant differences were found in Power Snatch, Snatch, Snatch Pull and Back Squat and C&J. Regarding peak velocity, significant differences were found in Power Snatch, Snatch, Snatch Pull and Back Squat. Regarding the mean velocity significant differences were found in Snatch Pull and Back Squat.

When genders were analysed separately, female group showed significant differences in Snatch ROM, Snatch Pull and Back Squat while in the male group, differences were found in the ROM of Snatch Pull, C&J and Clean. Regarding the mean power, female group presents significant differences in Snatch, Snatch Pull and Back Squat while the male group showed significant differences in mean power in C&J. The female group also revealed significant peak velocity differences in Snatch, Snatch Pull and Back Squat while the male group revealed significant differences in Power Snatch, Snatch and Snatch pull. In addition, the female group showed significant differences of mean velocity in Snatch, Snatch Pull and Back Squat (while the male group only showed significant differences in the C&J. The fact that women can perform a greater number of intermittent contractions than men even when the two groups are matched for strength has been reported [44] and the same may occur in OW training.

Considering all sample, almost all variables presented significant differences as well as moderate-to-large effect sizes values. Peak velocity seems to present the most significant differences in both groups, however on the female group, Snatch derivatives seem to show significant differences in every variable studied. This effect might be related to a better technique proficiency and consistency showed by female lifters. On the other hand, the male group only showed significant differences in peak velocity. The fatigue induced by each exercise may be related to the individualized load–velocity relationship and to specific characteristics of the participant [45,46]. Some studies [46,47] reported that the intersubject variability seems to be reduced when the loads are prescribed based on the individual load–velocity relationship. Some coaches prefer to prescribe the loads to match a specific number of repetitions rather than using a prescription method based on bar velocity. However, there is high intersubject variability in the number of repetitions performed to neuromuscular fatigue [48]

The only exercise that has not shown any difference in any variable was the Muscle Snatch, and this exercise was the one with the higher ROM. Higher barbell ROM have a direct relationship with the subject's height [11,12,49,50], meaning that if the lifter is taller, the barbell needs to have a higher displacement than if the lifter height is shorter. OW is a competitive sport that requires athletes to lift a maximal amount of weight in the Snatch and C&J. OW has its mainly distinction to sports training in velocity, meaning that other sports train towards developing more speed mostly, maintaining its load (bodyweight only in most cases). However, OW aims to maintain the ideal velocity for each exercise according to its height. Therefore, it is also correlated with lifter's height [49], while manipulating barbell weight could also indicate that OW lifters could be more resistant to velocity loss than other kind of athletes.

In this research topic, it is not common to analyse results of men and women together. The fact that we compared parameters in women and men as one homogeneous group could be considered questionable and should be considered as a study limitation. However, this methodological decision stems from the practical issue, that trainers test both men and women together [6].

Recent research also reported that different individual physical characteristics lead to different fatigue levels and recovery [50], and this could lead to a greater variability in the study results. More than half of the participants showed increases on most variables instead of the expected decrease by fatigue induced previously. The post-activation potential effect might be involved in these findings as this effect is a possible result of muscle contractions, and utilized during a subsequent explosive activity, it could potentially enhance power and therefore performance. However, once a previous effort might also induce fatigue, it is the balance between the post-activation potentiation effect and fatigue onset that will determine the effectiveness of a previous effort on performance in an explosive movement. This relationship is affected by several variables including, volume and intensity, and subject characteristics, as well as others [44,51]. Thus, it can also be inferred that probably some athletes did not quite induce this effect during their warm-up. The fact that the warm-up was not standardized can be considered a limitation herein. In future studies, the warm-up should be controlled and also equalized among subjects, since it may affect performance in explosive movements [52].

Additionally, we can speculate that some type of exercise may contribute more to a better potentiation of muscle contraction due to the lifted load, the force-velocity curve and also the different levels of induced fatigue [44,50,51,53-55]. The neuromuscular adaptations induced by weightlifting training strongly depends on the manipulation of the strength training variables, such as the exercise type and sequence, load magnitude, volume, interset and intraset rest periods, and lifting velocity [56,57]. A common concern for coaches is deciding how much weight their athletes should lift in a particular exercise as resistance training-induced adaptations are highly dependent on the intensity used [58].

Sports, such as OW along with its derivatives, require one single high force or high velocity effort. These movements typically involve a burst of concentric muscular activity of the agonist muscles followed by a phase of relaxation which during the motion continues due to stored momentum. This type of movements is also known as ballistic movements/actions [59]. In voluntary muscle contractions, the total force output of a muscle depends primarily on the number of motor units and the firing frequency of those motor units in which a higher force output will result in more motor units firing frequency [59]. In fact, motor unit recruitment is known to be a critical factor in maximal or ballistic contractions as well as in inducing fatigue. This way (ballistic), the size principle known to be the recruitment threshold of a motor neuron can directly be related to the size of its axon. In other words, the larger the axon, the bigger the amount of stimulation required [60]. In fact, there is some evidence of selective activation of large motor units if the motor task readily demands those motor units [61]. Moreover, ballistic exercises elicit several acute and chronic neurological changes. The standard recruitment of motor units, according to the size principle stays consistent at submaximal exercise intensities but appears to be violated in ballistic movements. It seems that the motor task more than any other variable determines the sequence of activation [59].

All OW exercises and their derivatives have relative high motor recruitment. However, more complex exercises require empirically more units. Therefore, they are supposed to use more energy, leading to a greater fatigue. The fact that some exercises did not show fatigue in the current study may be associated with the fact that volume or intensity fatigue threshold was not met. Recording the bar velocity at which submaximal loads are lifted is a potential method for quantifying the load as a function of the fatigue it causes [62,63]. Researchers have reported the general relationship between lifting velocity and the %1RM in different exercises. Nowadays, it seems to be a consensus that the individualized load–velocity relationship allows for a better assessment of athlete fatigue, mainly because the %1RM–velocity relationship is subject specific [64,65]. Unfortunately, little information exists regarding the possibility of predicting the number of repetitions from the recording of lifting velocity.

Some limitations of the present study may be considered, such as: randomization of the sample could only be accomplished to a certain extent since the population to be studied has a small number by itself and the inclusion criteria further narrows this choice. Thereafter, the small sample could also be pointed out as a relative limitation because both male and female were analysed as a group and even more when genders are separated. Moreover, specific warm-up wasn't standardized, mainly because lifters have their own warm-up routine, which we choose not to interfere. However, it may constitute another unaccountable variable, which could have influenced first and second SPT.

Future research should take the previous information into account and try to measure 1RM such as establishing it through determining catch height of each lifter, and setting 1RM, through the respective SPT height achievement.

5. Conclusions

This intervention confirmed our hypothesis that when volume and intensity are equated, there are differences between fatigue induced by various OW exercises.

In Snatch derivatives, peak velocity showed to be a good variable to quantify fatigue in both genders while all other variables only showed to be sensible in females. In addition, females seem more sensible to fatigue in Snatch derivatives. Snatch derivatives are well known for its velocity developing capability, therefore, fatigue may be explained more effectively, by a test that mimics the movement itself such as the SPT.

In C&J derivatives, females seem less likely to fatigue than males, therefore they can perform more volume and or intensity. Additionally, ROM seems to be the variable that we can better rely on and in addition, C&J derivative exercises are less velocity dependent, and this could explain the ROM capability to quantify fatigue.

The ten exercises studied showed different fatigue levels between them. However, it was not possible to quantify the magnitude of this fatigue.

Coaches may plan according to these findings, namely, as to C&J variables, by applying more load to females than to males, also, by using higher relative load on the exercises where fatigue was not found. Furthermore, using peak velocity in the Snatch and its derivatives plus ROM in the C&J and its derivatives seem to be best for training control in OW.

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Manuscript ID: healthcare-1994096
Type of manuscript: Article
Title: Comparison between Olympic Weightlifting Lifts and Derivatives for Fatigue Impact Quantification
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Kind regards,
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