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Optimal load and power spectrum during snatch and clean: differences between international and national weightlifters

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ABSTRACT

The aim of this study was to determine the optimal load (Pmax load) and optimal power spectrum (OPS) to achieve maximum power output (Pmax) during the snatch and clean with international weightlifters (IW) and national competitive weightlifters (NW). Twenty-two male weightlifters participated in two testing sessions. The first session involved performing one-repetition maximums (1RM) in the snatch and clean and second session assessed a power test across a spectrum of loads (30–90%) of each subject's 1RM in the predetermined exercises tested. Relative load had a significant effect on peak power, with Pmax load being obtained with 90% of 1RM for snatch and clean in the IW and 70 and 90% of 1RM for snatch and clean, respectively, in the NW. OPS was located between 80 and 90% for snatch and no OPS was found for the clean exercise in IW. In the NW, OPS was located between 70% up to 90% and 50% up to 90% in the snatch and clean, respectively. It may be advantageous to know the Pmax load and OPS in the snatch and clean when training to maximise power of weightlifters of different sport performance.

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1. Introduction

Power has been defined as the amount of work produced per unit of time (Hori, Newton, Nosaka, & Stone, 2005; Kawamori & Haff, 2004; Stone, Pierce, Sands, & Stone, 2006; Stone et al., 2003). During any exercise, Pmax is achieved through an optimal relationship between work and time (power = work/time). Weightlifting movements are known to elicit the greatest amount of power output of all resistance exercises (Kawamori & Haff, 2004; Suchomel, Comfort, & Stone, 2015), achieving these values during the second part of pull phase of the movement (Cormie, Mccaulley, Triplett, & Mcbride, 2007; Hori et al., 2005; Stone, 1993; Suchomel, Comfort, et al. 2015). Thus, the second pull of snatch and clean is known to elicit the greatest amount of power output of all resistance exercises (Cormie et al., 2007; Garhammer, 1993; Stone, 1993; Suchomel, Comfort, et al., 2015), accordingly weightlifting exercises are one of the most effective ways to develop power output (Lake, Mundy, & Comfort, 2014).

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The optimal load (Pmax load) is the load that elicits maximal power production in a certain movement (Cormie, McGuigan, & Newton, 2011). From a practical point of view, Pmax load and similar loads with no significant differences between them (defined as the optimal power spectrum) (Castillo et al., 2012) are considered the most appropriate stimuli to improve the power developed in a specific technical gesture (McBride, Triplett-McBride, Davie, & Newton, 2002). The Pmax load in weightlifting movements have been reported to occur with higher loads (described as percentage of 1RM) than in traditional resistance exercises (Castillo et al., 2012; Kawamori & Haff, 2004; McBride, Haines, & Kirby, 2011; Nacleiro, 2006; Suchomel, Beckham, & Wright, 2015; Suchomel, Comfort, et al., 2015). Because the Pmax attained varies with different relative loads (Kawamori & Haff, 2004), it is crucial that the load-power relationships of the snatch and clean should be examined in order to establish training recommendations for the use of these exercises.

Weightlifting success depends on how much weight the athlete can lift (1RM) and not on how much power the athlete can produce, however the importance of power production has been reported as a key factor in weightlifting. In that sense, Stone et al. (2006) claimed that power production is the most significant factor in determining success in weightlifting and likewise Hori et al. (2005) indicated that the success in weightlifting depends on the power applied to the barbell against high loads (high-load speed strength). According to previous studies (Garhammer, 1993; Stone, 1993; Stone et al., 2006), during weightlifting Pmax load is achieved with high loads, therefore, Pmax load is a key factor to achieve success during these types of exercises.

Some researchers have attempted to determine the percentage of 1RM that elicits maximal power output in some weightlifting movements but there is no uniform agreement between them (Comfort, Fletcher, & McMahon, 2012; Cormie et al., 2007; Kawamori & Haff, 2004; Suchomel, Beckham, et al., 2015). In that sense, it appears that the Pmax load is determined by multiple factors like the nature of the exercise and training status within a yearly training cycle (Kawamori & Haff, 2004), experience of the athlete, or strength background (Baker, Nance, & Moore, 2001a, 2001b; Nacleiro, 2006). These controversies with regard to the Pmax load could be partly explained by numerous methodological differences carried out in the studies such as the reporting of peak power vs. mean power development, equipment used (Cormie et al., 2007), inclusion of the barbell or entire system mass in calculation (McBride et al., 2011), strength level between athletes (Baker et al., 2001a, 2001b; Nacleiro, 2006) and technical proficiency (Nacleiro, 2006).

To date, the percentage of 1RM that yields maximal power output for the snatch is limited to one previously published study (Pennington, Laubach, de Marco, & Linderman, 2010). In addition, the other weightlifting movements studied have been usually variations of the classical weightlifting competition exercises: power clean (Comfort et al., 2012; Cormie et al., 2007; Kawamori et al., 2006; McBride et al., 2011; Pennington et al., 2010), hang power clean (Hori et al., 2007; Kilduff et al., 2007; Suchomel, Beckham, & Wright, 2014), hang high pull (Suchomel, Beckham, et al., 2015), push press (Lake et al. (2014) and back jerk (Flores, Sedano, & Redondo, 2017) in respect of which the subjects usually did not have technical mastery practising them. To our knowledge, no previous investigations have compared the Pmax load in the snatch and clean between weightlifters of different performance profiles. Hence, the aim of this investigation was to find Pmax load and optimal power spectrum (OPS) required to elicit Pmax during the snatch and clean in two groups; international weightlifters (IW) and national weightlifters (NW), comparing the differences between exercises and groups of performance. In line with research findings (Flores et al., 2017; Garhammer, 1993; Stone, 1993; Stone et al., 2006), it was hypothesised that there would be a strong relationship between these two exercises maximising Pmax towards the heavier end of the load-power curve (70–90% of 1RM) with the highest Pmax being achieved in the IW. Consequently, it would be useful to determine the Pmax load to optimise Pmax during the snatch and clean movements with different levels of performance in order to establish power training recommendations for weightlifters.

2. Methods

2.1. Subjects

Twenty-two male weightlifters participated in the study. The sample was divided in two groups taking into account the sports performance. The group 1; international weightlifters group (IW) was formed by 11 elite weightlifters (2 Hungarian, 4 Spanish and 5 Greeks), all of them have been members of their respective senior national teams on the current, or at least, the season before, participating in World or European Championship or Olympic Games (6 European Championship medallists, 1 World Championship medallist and 3 national current record holders). The group 2; national competitive weightlifters group (NW), was formed by 11 weightlifters (8 medallists at their National Championships in 2015 and/or 2016 seasons). On the basis of their best weightlifting performance in competition, their Sinclair coefficient was 395.69 ± 18.86 by the IW and 304.44 ± 27.07 by the NW (Sinclair, 1985). The descriptive characteristics of the weightlifters are shown in Table 1. Prior to participation in the study, all subjects read and signed an informed consent in accordance with guidelines set by the Human Subjects Review Committee at University of Salamanca. The study conformed to the principles of the World Medical Association's Declaration of Helsinki.

2.2. Procedures

Two test sessions were carried out in the weightlifters' usual training environment to record 1RM and barbell acceleration, which was subsequently used to calculate power. Before the

Table 1. Descriptive data for participant's characteristics (*M* ± SD).

Characteristics	IW (*n* = 11)	NW (*n* = 11)
Age (years)	24.18 ± 5.70	25.09 ± 6.10
Height (m)	175.18 ± 8.13	175.72 ± 4.80
Body mass (kg)	88.67 ± 27.49	82.67 ± 14.08
Sinclair coefficient	395.69 ± 18.86	304.44 ± 27.07
Weightlifting experience (years)	13.46 ± 8.20	13.27 ± 6.60
1RM (snatch/clean) (kg)		
Subject 1	(115/145)	(90/120)
Subject 2	(156/170)	(130/150)
Subject 3	(148/185)	(110/140)
Subject 4	(100/130)	(90/120)
Subject 5	(125/155)	(100/120)
Subject 6	(130/200)	(100/115)
Subject 7	(155/188)	(110/130)
Subject 8	(140/170)	(110/132)
Subject 9	(100/120)	(115/135)
Subject 10	(120/150)	(122/146)
Subject 11	(160/190)	(102/115)

start of each test session, participants went through a standardised warm-up composed of 5 min of light-intensity cycling followed by 5 min of a series of dynamic stretches. After this general warm-up, participants engaged in 10 min of specific warm-up involving the actual movement of the snatch and clean. In both sessions the order of the exercises assessed was snatch followed by clean, and a 10-min rest was allowed between exercises. This recovery period is similar to that applied in weightlifting competitions between the snatch and the clean and jerk.

2.2.1. 1RM testing

The subjects' 1RM was obtained for the snatch and clean following the standardised protocol presented by Baechle and Earle (Baechle & Earle, 2008). The weightlifters had previously performed 1RM tests numerous times and therefore were well accustomed to the procedures for the test.

2.2.2. Power testing

2–4 days after their 1RM was established, a power test session was performed. After the warm-up exercise sets, subjects carried out a maximum effort repetition with each load, which was systematically increased to 30, 40, 50, 60, 70, 80 and 90% of the subject's predetermined 1RM. The recovery period between loads was determined by the athlete, but was in all cases between 3 and 5 min. A 3-axis accelerometer (PS-2136A, PASCO, Roseville, CA) operating at 100 Hz and a Bluetooth wireless device (Airlink 2 PS-2010, PASCO, Roseville, CA) were used in the power testing. Previous studies showed that 100 Hz is an appropriate sampling rate to record weightlifting exercises (Sato, Smith, & Sands, 2009). The reliability of the results offered by these tests with the current measuring protocol was previously validated by Flores, Sedano, de Benito, and Redondo (2016). This device was chosen for its easy portability in the weights room and minimal disturbance of the flow of the lifting sessions without compromising the weightlifter's technique in data collection (Sato et al., 2009). The accelerometer was placed on the bar according to the procedures explained by Flores et al. (2016) (Figure 1).

The data were processed thereafter, using Pasco Capstone software (Version 1.1.5, Pasco Scientific PASCO, Roseville, CA) and barbell peak power outputs (highest instantaneous value during each lift) were calculated from acceleration according to the methodology previously explained by Thompson and Bemben (Thompson & Bemben, 1999). According to Flores et al. (2016) data analysis included only the vertical acceleration attained by the barbell that was lifted, but only up to the finish of pull phase of the exercises assessed. It should be noted that the lifter's body weight was not included in the calculations, so that the power calculations recorded the work done against the bar by the lifter. The exclusion of the body weight in the calculations gives more important information about weightlifting performance because, although the lifters have to accelerate their body mass throughout the lifts, the centre of gravity of the barbell and the system (bar plus body mass) move independently of one another and the success of weightlifting depends on the power applied to the barbell regardless of the lifter's body mass (Hori et al., 2007; McBride et al., 2011). Moreover, according to McBride et al. (2011) peak power is very similar for the bar, body, and system (bar plus body mass) thus, although the methodology used would have few, if any, training implications (McBride et al., 2011), the methodology chosen to determine the Pmax load should depend on the characteristics of the sport itself. In that sense, to measure

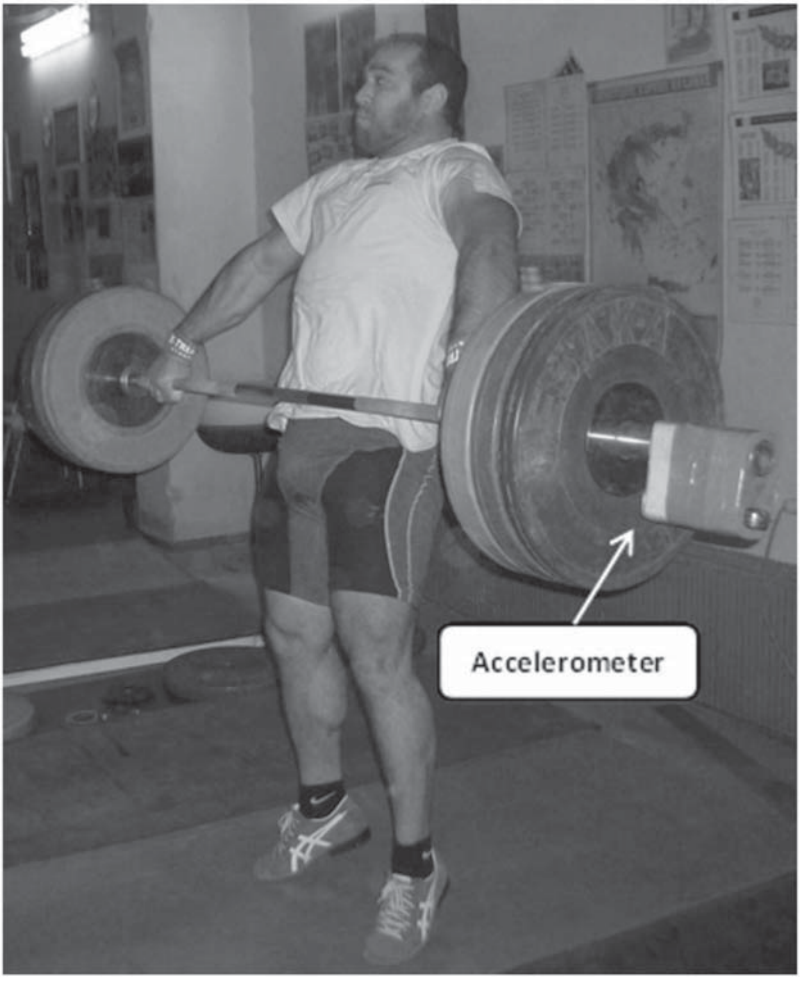

Figure 1. Weightlifter performs a lift with the accelerometer fixed to the bar according to the established protocol by Flores et al. (2016).

specifically the power applied to the barbell may be the primary outcome measure when assessing sports involving the movement of an external object (i.e. weightlifting) (Hori et al., 2007; McBride et al., 2011).

Participants were allowed to use the hook grip, chalk, weightlifting belt and weightlifting shoes, but were not allowed to use weightlifting straps. Strong verbal encouragement was given to all participants to motivate them to perform each lift as maximally and as powerfully as possible.

3. Statistical analyses

Normality of distribution was tested by means of the Kolmogorov–Smirnov test. Standard statistical methods were used to calculate the mean ± s. Repeated measures two-way analysis of variance (ANOVA) (factors: load and lift) and two-way ANOVA with repeated measurements (factors: load and group) were used to analyse peak power with loads of 30–90% and, power-related effects and the differences between level groups, respectively. When a significant *F* value was achieved by means of Wilks' lambda, Scheffe's *post hoc* procedures were performed to locate the pairwise differences. The Bonferroni correction for multiple comparisons was applied. Additionally, Cohen's *d* (Cohen, 1988) effect sizes and 95% confidence intervals were estimated for each variable. A significance level of .05 was adopted for all statistical tests that were performed in the program SPSS version 18.0 (Chicago, IL, USA).

4. Results

The Kolmogorov–Smirnov test shown that all variables were distributed normally ($p > .05$).

4.1. Snatch and clean: comparison between level groups

The results of snatch and clean comparison between both levels of performance are presented in Table 2. In both exercises and all loads assessed IW shown higher values of peak power than NW. Significant differences "load × group" ($p < .01$, $d = .44$) were exhibited between IW and NW in the snatch above the 50% of 1RM (Figure 2). ANOVA revealed significant "load × group" interaction effects for clean (Figure 2) above the 70% of 1RM ($p < .05$, $d = .15$).

Table 2. Descriptive data for power for snatch and clean for each test occasion and level group.[a]

		Peak power (W)		95% Confidence interval	
Load (% 1RM)	Group	Snatch	Clean	Lower bound	Upper Bound
30	IW	2053.87 ± 413.99†		1735.65	2372.09
			2031.66 ± 501.99†	1694.42	2368.90
	NW	1843.82 ± 575.49†		1401.46	2286.18
			1670.35 ± 407.33†	1396.70	1944.00
40	IW	2521.23 ± 456.11†		2170.63	2871.83
			2433.65 ± 643.04†	2001.65	2865.65
	NW	2394.83 ± 510.66†		2002.31	2787.36
			2127.25 ± 414.63†	1848.70	2405.81
50	IW	2859.22 ± 288.53†		2637.44	3081.01
			2911.69 ± 682.32†	2453.30	3370.08
	NW	2749.73 ± 611.29†		2279.85	3219.61
			2587.93 ± 615.58	2174.38	3001.49
60	IW	3479.47 ± 774.80†		2883.91	4075.04
			3169.12 ± 640.57†	2738.78	3599.46
	NW	2874.55 ± 325.27†		2624.52	3124.57
			2667.97 ± 470.15	2352.12	2983.82
70	IW	3603.56 ± 770.24†		3011.50	4195.63
			3205.25 ± 662.58†	2760.12	3650.38
	NW	3084.40 ± 430.32		2753.63	3415.18
			2885.18 ± 479.20	2563.25	3207.11
80	IW	3961.87 ± 997.14		3195.40	4728.33
			3521.65 ± 739.57†	3024.81	4018.50
	NW	3075.28 ± 485.58		2702.03	3448.53
			2833.56 ± 491.04	2503.68	3163.45
90	IW	4185.86 ± 1061.79		3369.70	5002.03
			3753.08 ± 843.39	3186.48	4319.68
	NW	3014.20 ± 383.54		2719.38	3309.01
			2919.74 ± 531.14	2562.91	3276.56

[a]Values are given as mean ± SD.
†Significantly different ($p < .001$) from Pmax load.

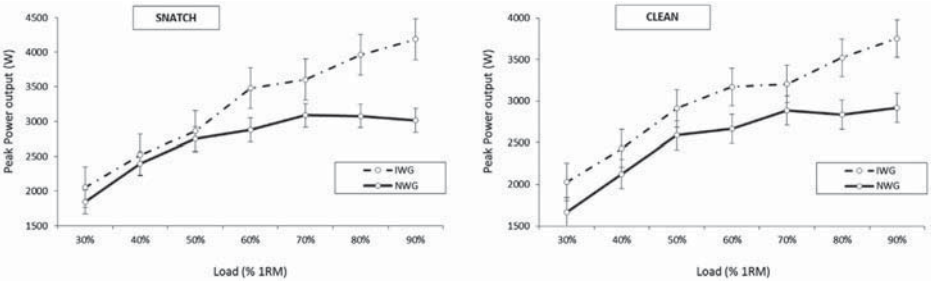

Figure 2. Peak power output at loads of 30–90% of one repetition maximun (1RM) during snatch and clean for IW and NW.
Note: Significant differences between IWF and NWF for 80 and 90% in snatch and clean.

4.2. The effect of load on the international weightlifters group

For snatch, significant differences "load × lift" ($p < .01$, $d = .97$) were exhibited between loads of 30–90% and Scheffe's *post hoc* tests found differences between 90% (Pmax load) and 30% ($p < .01$, $d = 2.54$), 40% ($p < .01$, $d = 1.88$), 50% ($p < .01$, $d = 1.64$), 60% ($p < .01$, $d = .77$), and 70% ($p < .01$, $d = .59$). For clean, ANOVA revealed significant "load × lift" ($p < .01$, $d = .97$) interaction effects and Scheffe's *post hoc* tests located the differences between 90% and 30% ($p < .01$, $d = 2.48$), 40% ($p < .01$, $d = 1.76$), 50% ($p < .01$, $d = 1.09$), 60% ($p < .05$, $d = .78$), 70% ($p < .01$, $d = .72$) and 80% ($p < .05$, $d = .29$).

Snatch and clean peak power increased from 30% up to 90% of 1RM achieving the highest power values with 90% of 1RM in both exercises. Table 2 shows the peak power obtained for IW across all loading conditions for the snatch and clean. The Pmax for snatch was 4185.86 ± 724.45 W and 3753.08 ± 557.56 W for clean exercise.

Snatch and clean Pmax was observed with the 90% of 1RM for IW. In the snatch, no significant differences were found between 90% (Pmax load) and 80% of 1RM identifying this interval as the OPS for this exercise and group (Figure 3). In the clean significant differences were observed between the 90% (Pmax load) of 1RM and all spectrum of loads assessed (Figure 3).

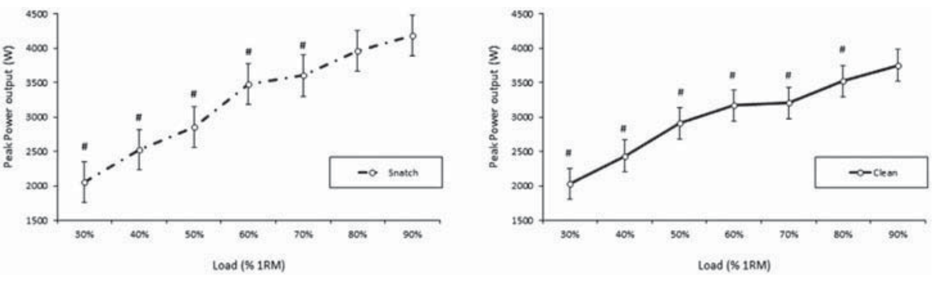

Figure 3. Peak power output at loads of 30–90% of one repetition maximun (1RM) during snatch and clean for IW.
Note: # = significant diferent from Pmax load (90% in both exercises).

4.3. The effect of load on the national weightlifters group

For snatch, ANOVA reflected significant "load × lift" interaction effects ($p < .01$, $d = .98$) and Scheffe's *post hoc* tests located the differences between 70% and 30% ($p < .01$, $d = 2.44$), 40% ($p < .01$, $d = 1.56$), 50% ($p < .05$, $d = .68$) and 60% ($p < .05$, $d = .65$) and for clean the significant differences ($p < .01$, $d = .98$) and Scheffe's *post hoc* tests only registered differences between 90% and 30% ($p < .01$, $d = 2.48$), 40% ($p < .01$, $d = 1.40$) and 50% ($p < .05$, $d = .49$).

Snatch and clean peak power increased from 30% up to 70% of 1RM in both exercises. Table 2 shows the peak power obtained for NW across all loading conditions for the snatch and clean. The Pmax for the snatch was 3084.40 ± 421.52 W achieved with 70% of 1RM and the Pmax for the clean was 2919.74 ± 429.91 W achieved with 90% of 1RM.

For the NW snatch and clean Pmax was observed with the 70 and 90% of 1RM, respectively. In the snatch, no significant differences were found between 70%, (Pmax load) 80% and 90% of 1RM identifying this interval (70–90%) as the OPS for this exercise and group (Figure 4). In the clean no significant differences were observed between 90% (Pmax load) and 80, 70, 60 and 50% of 1RM identifying this interval (50–90%) as the OPS for this exercise and group (Figure 4).

5. Discussion

The purpose of this research was to determine the optimal load (Pmax load) and OPS in the snatch and clean exercises comparing the differences between international weightlifters (IW) and national competitive weightlifters (NW). The Pmax load was observed with 90% of 1RM for snatch and clean in the IW and 70 and 90% of 1RM for snatch and clean, respectively in the NW. In the IW, OPS occurred between 80% and 90% of 1RM in the snatch and no OPS was found for the clean exercise. In NW, OPS was found between 70 and 90% of 1RM in snatch and between 50 and 90% for clean exercise. According to our initial hypothesis, the findings of this study support the importance of the load percentage to achieve Pmax load being this percentage specific of each exercise. In addition, Pmax generated during the snatch and clean by IW were higher than generated by NW and with higher percentages of 1RM.

Training in weightlifting focuses on generating high levels of muscular power during the lift as well as to transfer that power to the bar in a short period of time (Campos, Poletaev,

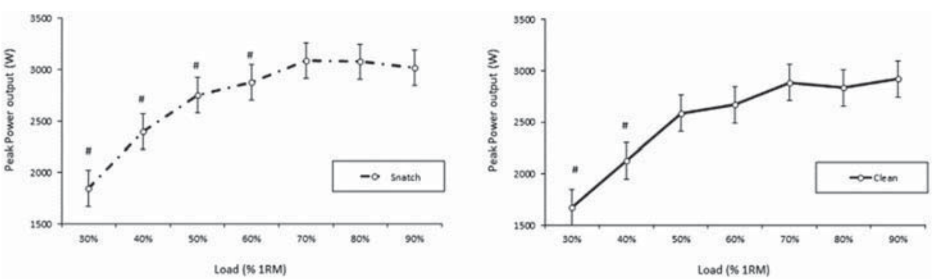

Figure 4. Peak power output at loads of 30–90% of one repetition maximun (1RM) during snatch and clean for NW.

Note: # = significantly different from Pmax load (70% for snatch and 90% for clean).

Cuesta, Pablos, & Carratala, 2006). During weightlifting exercises, such as snatch, clean, jerk, and variations of these movements, the centre of gravity of the barbell and the system (bar plus body mass) do not move in parallel (Cormie et al., 2007; McBride et al., 2011). According to this, one of the weightlifter's objectives is moving an external object, the barbell mass, as fast as possible because the success of weightlifting depends on the power applied to the barbell (Hori et al., 2007; McBride et al., 2011). Taking into account only the power applied to the barbell, Pmax load during weightlifting exercises and their derivatives has been reported ranging from 70 to 90% of 1RM (Flores et al., 2017; Haines et al., 2010; Nacleiro, 2006; Pennington et al., 2010).

The present study confirm that in weightlifters of international and national competitive levels, the Pmax load during snatch and clean is achieved with higher percentages of 1RM than Pmax load reported previously during traditional resistance exercises (Castillo et al., 2012; Kawamori & Haff, 2004; McBride et al., 2011; Nacleiro, 2006; Suchomel, Beckham, et al., 2015; Suchomel, Comfort, et al., 2015). In the current work, IW achieved the Pmax load with 90% of 1RM during the snatch and clean and the OPS was located at the top of power load curve studied during the snatch. On the other hand, NW shown wider OPS (from 70% up to 90% for the snatch and from 50% up to 90% for the clean) being these results in line with other studies where no statistically significant differences were reported between the Pmax load and loads ranging from 60 to 80% of 1RM, in power clean (Comfort et al., 2012) or from 50 to 90% of 1RM, in power clean and hang power clean (Cormie et al., 2007; Kilduff et al., 2007). However, it is necessary to be aware of comparing the results of these investigations with the present study because different systems to take data, methodologies and forms to calculate power (inverse and forward dynamics) have been used.

The results of the current study to achieve Pmax load (90% of 1RM in snatch and clean for IW and clean for NW) was the same result reported by McBride et al. (2011) using power clean. In this regard the authors of the current study found the same percentage to reach Pmax load in a previous study carried out using the same measurement system and methodology during exercises of jerk and back jerk in a group of competitive weightlifters (Flores et al., 2017).

The high percentage of 1RM found in the present study to achieve Pmax load might be influenced by the strength profile of the subjects (international and national competitive weightlifters). Thus, it has been suggested that the level of experience and proficiency of the athletes could be expected to shift the percentage of maximum strength at which the highest power is produced either upward or downward (Kawamori & Haff, 2004; Nacleiro, 2006). In this way, the strength level of the athletes could be a confounding factor (Kilduff et al., 2007). For example, in line with the current study, Stone et al. (2003) found that in squat jumps weaker athletes produced the maximal power output at a lower relative load than did stronger. The same trend was reported by Kilduff et al. (2007) using hang power clean exercises with professional rugby players. However, there is no uniform agreement between researchers and contradictory results were reported by others authors (Baker et al., 2001a, 2001b), suggesting that stronger athletes used lower percentages of 1RM than weaker to maximise power output during jump squats and bench press throw. However, in order to compare the results of these studies it should be taken into account the different methodologies used, because the various results would be influenced by the type of methodology applied in each of them. In that sense, Kilduff et al. (2007) reported the peak power calculated through forward dynamics, Stone et al. (2003) reported the peak power calculated through inverse dynamics while, Baker et al. (2001a, 2001b) used inverse dynamics to report the average mechanical power.

The lower percentage to achieve Pmax load in the present study was found in the snatch for NW with 70% of 1RM. Although no statistical differences were revealed between 70% up to 90% of 1RM, this lower percentage to achieve Pmax load could be explained by the most difficult technique of snatch (Gourgoulis, Aggelousis, Mavromatis, & Garas, 2000; Nacleiro, 2006) and the lower sport level of NW.

The power data obtained at the present work are findings significantly lower than those previously reported by Stone (1993) and Garhammer (1993) (5600 W and almost 7000 W respectively). These discrepancies might be attributable to variations in the methodological procedures used (Hori et al., 2007; McBride et al., 2011; Stone, 1993), like how to collect and analyse power output, the sampling rate, the body mass of the athletes, the use of average power or peak power or the conditions for data collection. In the current study the body mass of the sample was 88.67 ± 27.49 kg for IW and 82.67 ± 14.08 kg for NW which is much less than the 100 kg and 125 kg of the lifters studied by Stone (1993) and Garhammer (1993), respectively. In addition, these previous works reported the average power through video analysis under competition conditions, while in the current study the evaluation of peak power was carried out in training conditions. Moreover, in the present study the horizontal component and the work performed by displacing the lifter's centre of mass were not taken into account. These differences could well be decisive in explaining the variability reported in the power values in these studies. On the other hand, the current findings are in line to the preceding results of Garhammer (1991) who identified the average power output generated during a snatch lift ranges from 1300 to 4000 W among elite male lifters, similar sample comparing to IW of the present work.

According to Garhammer (1993) horizontal component during weightlifting is usually small but not always negligible because some weightlifters generate large horizontal barbell accelerations at the beginning of the second pull during snatch and clean. During the current study the work performed horizontally displacing the barbell was rejected taking into account only the vertical component according with the methodology previously validated by Flores et al. (2016). According to Garhammer (1993), the horizontal work produced by a lifter of a light weight division represents a small component lesser than 5 % of the total work produced, being this component for heavy weight divisions around 10 % of the total work. During the current study the body mass of the sample was 88.67 ± 27.49 kg for IW and 82.67 ± 14.08 kg for NGW (Table 1). These values would be included within of middle body weight divisions in weightlifting and although according to Garhammer (1993) the weightlifters included in these categories would not generate maximum horizontal component values (around 10%), this fact should be kept in mind by the reader of this study. This neglect of the horizontal component of work during the current study should be taken into account to compare works where horizontal and vertical components have been studied together.

The results of the present study, taken together with the details given above, suggest that weightlifting movements and their variations require a heavier relative load to maximise power output in weightlifters. According to Lake et al. (2014) this might be explained by the fact that, although ballistic, load projection must be performed under control and within technical patterns, which may prevent achieving maximum power outputs with lighter loads. It is likely that this idea could explain why the weightlifters are unable to apply the maximum velocity possible to the bar with lighter loads. Thus, loads below 80% of 1RM analysed in the present work were probably not performed with maximal intent, as this would result in the participants performing power snatch or power clean and not snatch or clean. In that sense, González-Badillo (1991) claimed that a correct technical execution should allow lifting the 85% of 1RM of snatch or clean in power snatch or power clean, respectively, for good balanced weightlifters.

As hypothesised, the results of the current investigation demonstrate that elicited Pmax in IW is greater than in NW at all loads assessed, being these differences statistically significant at the top of the power load curve (Figure 2). This could be explained by the higher level of performance of IW, exhibiting a better ability to develop high power values with high percentages of loads where the technical mastery of movement is key to ensuring a successful lift (Gourgoulis et al., 2000).

The results of this study should be considered in light of a few limitations. Firstly, the peak power is referred only to the vertical component of the bar. Although according to Garhammer (1993) horizontal work is usually small for weightlifting, even negligible during the jerk, some weightlifters generate large horizontal accelerations at the beginning of the second pull for snatch or clean lift, which was not taken into account in this study. Secondly, due to the methods used to calculate power (inverse dynamics based on barbell displacement) the findings of this study are mainly applicable to sports where to move an external mass as fast as possible is the main goal (e.g. throwing or weightlifting) but it less applicable to other (e.g. sprinting or jumping) where power production against one's own body is crucial to achieve high performance (McBride et al., 2011). And finally, power against 100% of 1RM was not assessed so we cannot conclude definitely that 90% is the Pmax load. Future studies may identify roundly the Pmax load including the evaluation power with 100% of 1RM.

6. Conclusion

If the load control is essential to ensure the specificity of results and training adaptations (Jandacka & Uchytil, 2011), and Pmax loads are specific to each exercise (Soriano, Jiménez-Reyes, Rhea, & Marín, 2015), it is important for coaches to be aware of the Pmax load and OPS of the snatch and clean exercises according to the different performance of the athletes. Based on the outcomes of this investigation, it is recommended that international weightlifters use loads between 80 and 90% of 1RM in snatch and clean to improve their power output in these exercises. On the other hand, competitive weightlifters of national level could benefit from using lower loads in a wider spectrum of loads, 50–90% of 1RM in clean and 70–90% of 1RM in snatch when setting out training programmes to improve the power output.

Disclosure statement

No potential conflict of interest was reported by the authors.

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