

The Optimal Load for Maximal Power Production During Upper-Body Resistance Exercises: A Meta-Analysis

Marco Antonio Soriano¹ · Timothy J. Suchome² · Pedro J. Marín¹

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Abstract

Background External mechanical power is considered to be one of the most important characteristics with regard to sport performance.

Objective The purpose of this meta-analysis was to examine the effect of load on kinetic variables such as mean and peak power during bench press and bench press throw, thus integrating the findings of various studies to provide the strength and conditioning professional with more reliable evidence upon which to base their program design.

Methods A search of electronic databases (MEDLINE, PubMed, Google Scholar, and Web of Science) was conducted to identify all publications up to 31 October 2015. Hedges' g (95 % confidence interval) was estimated using a weighted random-effect model, due to the heterogeneity (I^2) of the studies. Egger's test was used to evaluate possible publication bias in the meta-analysis. A total of 11 studies with 434 subjects and 7680 effect sizes met the inclusion criterion and were included in the statistical analyses. Load in each study was labeled as one of three intensity zones: zone 1 represented an average intensity ranging from 0 to 30 % of one repetition maximum (1RM); zone 2 between 30 and 70 % of 1RM; and zone 3 \geq 70 % of 1RM.

Results These results showed different optimal loads for each exercise examined. Moderate loads (from >30 to <70 % of 1RM) appear to provide the optimal load for peak power and mean power in the bench press exercise.

Lighter loads (<30 % of 1RM) appear to provide the highest mean and highest peak power production in the bench press throw exercise. However, a substantial heterogeneity was detected $I^2 > 75$ %.

Conclusion The current meta-analysis of published literature provides evidence for exercise-specific optimal power loading for upper body exercises.

Key Points

Moderate loads from >30 to <70 % of one repetition maximum (1RM) appear to provide the optimal load range for mean and peak power production during the bench press exercise.

Lighter loads (\leq 30 % 1RM) appear to provide the optimal load range for mean and peak power production during the bench press throw.

Optimal load ranges for mean and peak power production are exercise specific.

1 Introduction

External mechanical power has been noted as an important performance characteristic that relates to the superior performance of athletes [1, 2]. In fact, previous research has indicated that external mechanical power may be a primary factor that differentiates the performance between athletes in sports [3–5]. As a result, the development and improvement of external mechanical power has become the focus of many strength and conditioning programs. In order to effectively

✉ Pedro J. Marín
pjmarin@cymori.com

¹ CyMO Research Institute, Avda. del Estadio, 17, Laguna de Duero, Valladolid 47140, Castilla y León, Spain

² Department of Human Movement Sciences, Carroll University, 100 N. East Ave, Waukesha, WI 53186, USA

prescribe a training stimulus that will elicit positive adaptations in external mechanical power, an evidence-based approach should be taken. Therefore, research that examines various training stimuli may aid in the selection of the most appropriate training method for the development of external mechanical power.

It has been suggested that athletes who train at loads that maximize external mechanical power may produce the greatest enhancements in dynamic athletic performance [6]. Additional research indicated that training at loads that produced the greatest power output may provide the best stimulus for further improvements in power [7–9]. A recent meta-analysis examined the optimal load for maximal external mechanical power during various lower body exercises [10]. While the influence of various external loads on lower body external mechanical power has been frequently studied within the scientific literature, less is known about upper body exercises such as the bench press and bench press throw. Cronin et al. [11] examined the influence of contraction type and movement type on external mechanical power during a concentric-only bench press, concentric-only bench press throw, rebound bench press, and rebound bench press throw across loads of 30–80 % of one repetition maximum (1RM). The results of their study indicated that exercise-specific loads that maximized power output may exist for each exercise, suggesting that the load–power relationship may vary based on the biomechanical differences between exercises. Previous research has examined the optimal load for the bench press [12, 13] and bench press throw [11, 14–16]. Collectively, the studies indicate that maximal power output may occur anywhere between 30 and 80 % 1RM for both exercises. The wide range of recommended loads is problematic for effectively prescribing suitable loads to maximize external mechanical power for each exercise. Therefore, it appears that an analysis that includes a larger number of studies is warranted in order to narrow the loading ranges for each exercise to allow for appropriate loading recommendations.

A previous review by Castillo et al. [17] provided an overview of optimal loading during bench press variations. However, as additional studies that examine external mechanical power during upper body exercises are added to the scientific literature, it becomes possible for quantitative reviews to integrate and evaluate the findings of each individual study with the intent of identifying the appropriate training parameters for maximal power production. The meta-analysis serves as a method to combine the results of numerous studies [18]. The purpose of this meta-analysis was to examine the effect that different loads have on mean and peak power production in several upper body exercises by integrating the findings of the included studies. The results from this analysis may provide strength and conditioning practitioners with reliable evidence to better inform their programming.

2 Methods

2.1 Literature Search

A search of electronic databases was conducted to identify all publications that investigated maximum peak and mean mechanical power up to 31 October 2015. As a prerequisite, all studies were performed in healthy sports populations including both adolescents and adults (>15 years). The literature search was undertaken using 14 different keywords: “mechanical power”, “maximum power”, “power production”, “power training”, “weight training”, “power development”, “peak power”, “mean power”, “average power”, “optimal load”, “power-load curve”, “upper body”, “bench press”, “bench press throw”. Search terms were combined by Boolean logic (AND, OR), with no restrictions on date or language, in MEDLINE, PubMed, Google Scholar, and Web of Science. We also extended the search spectrum to “related articles” and the bibliographies of all retrieved studies. The authors of published papers were also contacted directly if crucial data were not reported in original papers.

2.2 Inclusion and Exclusion Criteria

The following inclusion criteria were used to select articles for the meta-analysis:

1. The study must have used absolute loads or relative to 1 RM (maximal strength) in the procedures. In addition, the data must also be written in the text, tables, or shown in figures.
2. The study must report “peak power” or “mean power.” Throughout the literature, the terms “peak power” and “mean power” have been used frequently for analyzing upper body power development [4, 12, 14, 19].
3. The study must have analyzed the power-load spectrum and/or conducted a measure of different loads across the power-load spectrum.
4. The exercises must have been performed under Smith machine conditions and the measurement system must have used a kinematic method such as a transducer and derivations. This method is one of the most commonly used to research power development during upper body resistance exercises through displacement data [20, 21]. Therefore, it is important to highlight the role of the Smith machine in this system as a means of providing a more accurate measurement of power development by restricting movements to the vertical plane and eliminating measurement errors resulting from horizontal movement [20, 21].

2.3 Methodological Quality of Included Studies

Study quality was evaluated by a modified standard procedure from Soriano et al. [10] (see Table 1). Each study was read and ranked, with a larger number indicating better quality. For each question, a 1 was awarded if the study met the standard. If an insufficient description or data were provided to analyze a specific question, a 0 was awarded. The score was then tallied for each of the questions, with the highest score possible equaling 5 out of 5.

2.4 Statistical Methods and Data Extraction

For each study, standardized mean differences (Hedges' g) and 95 % confidence intervals (CIs) were computed separately. This was done based on the difference in performance between the training zone and the pooled standard deviation. Hedges' g (95 % CI) was estimated using a weighted random-effect model. The overall outcome for the analyzed conditions was assessed by calculating weighted g averages. The criterion for statistical significance was defined as

$P < 0.05$. Since no available meta-analytic evidence favored any power-load model during upper-body resistance exercises (Table 2), we used comparisons (zone 1 vs. zone 2, zone 1 vs. zone 3, and zone 2 vs. zone 3). Zone 1 was defined as 0–30 % 1RM; zone 2 as >30 % 1RM to <70 % 1RM; and zone 3 as ≥ 70 % 1RM. Comprehensive meta-analysis software (version 2.2.04, Biostat, Englewood, NJ, USA) was used for all analyses and pooled estimates were calculated using a random-effects model, due to the heterogeneity (I^2) of the studies. Egger's test was then used to evaluate possible publication bias in the meta-analysis with the number of included studies >2 .

3 Results

3.1 Study Characteristics

A flow diagram of the literature search is shown in Fig. 1. According to the inclusion criteria defined above, we identified 11 independent studies (434 subjects). An

Table 1 List of criteria for assessment of the methodological quality

No.	Item	Score
1	Sample description Characteristics of the subjects (age, weight, height, sex) Definition of the population (athlete, recreationally trained or active subjects, and untrained or sedentary subjects) Training status and training years in strength or power training	0 or 1
2	Procedure description Detailed description of the test (exercises performed on loading conditions) Feedback for maximizing performance (“as fast as possible,” “as high as possible,” “quickly,” “explosively”) Detailed description of the intervention protocol (randomized order of exercises, enough recovery between exercises, performed exercises in the same order for all subjects) Developed a familiarization period with the test (last weeks or last days before the assessment)	0 or 1
3	Intervention Defined exercise technique (angle of the joint, bar displacement and position, location of the grip, location of the back and feet across lifting) Defined loading conditions Defined number of trials for each lift Defined adequate recovery between trials across all lifts	0 or 1
4	Measurement system, data collection, and data analysis Instrument description (brand of the instrument, model, origin country) Defined sampling frequency of the instrument Defined and developed reliability of the test Defined configuration and variable calculation of the instrument Defined collection software for recording and analyzing data	0 or 1
5	Results detailed Measure of the central tendency Amount of variation or dispersion from the average	0 or 1

Table 2 Bench press and bench press throw descriptions

Exercise	Description
Bench press	<p>Subjects started by lying in a supine position on a flat bench and positioning their hands on the barbell slightly wider than shoulder width apart. After their hands have been properly placed, two primary methods were used to perform a bench press repetition</p> <ol style="list-style-type: none"> 1. Subjects were instructed to lower the barbell to their chest and immediately press the barbell to full elbow extension. This method utilized the stretch-shortening cycle [12, 14] 2. Subjects were instructed to lower the barbell to their chest and after a momentary pause, they pressed the barbell to full elbow extension. This method minimized the stretch-shortening cycle and was performed using a concentric-only muscle action [21, 25]. Another method eliminated the lowering phase by positioning the barbell on the subject's chest [14] <p>In addition, during each lift subjects were required to keep their head, shoulders, and trunk in contact with the bench and their feet on the floor or bench</p>
Bench press throw	<p>Subjects started by lying in a supine position on a flat bench and positioning their hands on the barbell slightly wider than shoulder width apart. After their hands have been properly placed, two primary methods were used to perform a bench press throw repetition</p> <ol style="list-style-type: none"> 1. Subjects were instructed to lower the barbell to their chest and immediately press the barbell and throw it as high as possible by releasing the bar at the top of the range of motion. This method utilized the stretch-shortening cycle [14, 16, 27] 2. The barbell was positioned at the subject's chest height and eliminated the lowering phase. The subjects were instructed to press the barbell to full elbow extension and throw it as high as possible by releasing the bar at the top of the range of motion [12, 14]. This method minimized the stretch-shortening cycle and was performed using a concentric-only muscle action <p>Furthermore, during each lift subjects were required to keep their head, shoulders, and trunk in contact with the bench and their feet on the floor or bench</p>

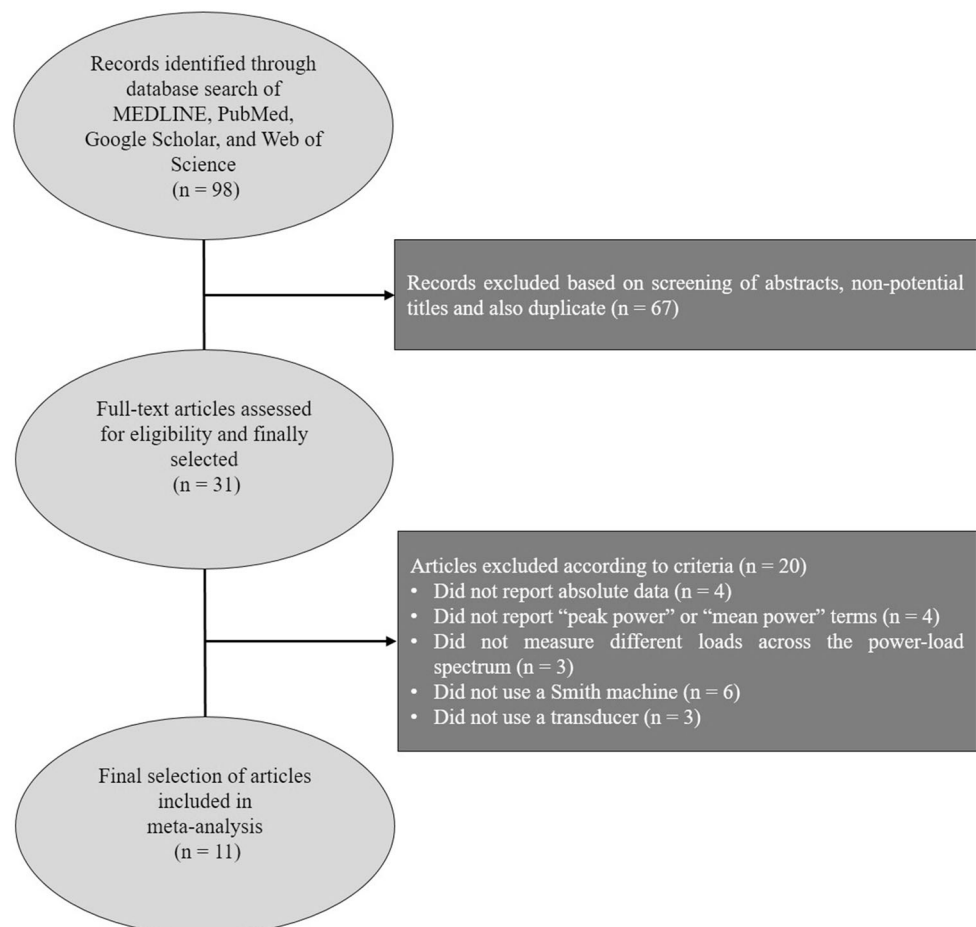
Fig. 1 Flow diagram of the literature search

Table 3 Descriptive characteristics of studies

Study	<i>n</i>	Sample description	Training status	Procedure	Measurement system	Power-load spectrum	Score
Pearson et al. [24]	12 M	Age: 33.9 ± 25.5 years BW: 97.8 ± 12.5 kg Elite sailors	≥3 years S-P experience 1RM BP: 119.7 ± 23.9 kg	BP (SM)	LPT (1) 500 Hz	10, 20, 30, 40, 50, 60, 70, 80, 90, 100 % 1RM (CO)	4
Gorostiaga et al. [23]	30 M	G1 = 15 Age: 31 ± 3 years BW: 95.2 ± 13 kg Elite handball players G2 = 15 Age: 22.2 ± 4 years BW: 82.4 ± 10 kg Amateur handball players	G1 = 15 No specified time in S-P experience 1RM BP: 106.9 ± 11.6 kg G2 = 15 No specified time in S-P experience 1RM BP: 82.5 ± 14.8 kg	BP (SM)	RE (no specified brand) 500 Hz	30, 45, 60, 70 % 1RM (CO)	4
Argus et al. [27]	26 M	Age: 24 ± 2.3 years BW: 101.1 ± 10.1 kg Elite rugby union players	≥2 years S-P experience 1RM BP: 121.7 ± 19.2 kg	BPT (SM)	OE (2) 50 Hz	20, 30, 40, 50, 60 % 1RM (SSC)	5
Sanchez-Medina et al. [21]	100 M	Age: 25.1 ± 5 years BW: 79.4 ± 8.3 kg Recreationally trained	≥2 years S-P experience 1RM BP: 98.7 ± 12.5 kg	BP (SM)	LPT (3) 1000 Hz	20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100 % (CO)	5
Sanchez-Medina et al. [19]	75 M	Age: 26.7 ± 5.4 years BW: 76 ± 8.8 kg Recreationally trained	≥2 months S-P experience. 1RM BP: 90.3 ± 16.3 kg	BP (SM)	LPT (3) 1000 Hz	20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100 % (CO)	5
Thomas et al. [15]	19 M	Age: 20 ± 2 years BW: 77.6 ± 7.1 kg Soccer players (NCAA Division 1)	≥1 year S-P experience 1RM BP: 84.9 ± 17.1 kg	BPT (SM)	RE (4) 500 Hz	30, 40, 50, 60, 70 % 1RM (SSC)	5
Newton et al. [14]	17 M	Age: 20.6 ± 1.9 years BW: 83.7 ± 8.2 kg Exercise science students	≥6 months S-P experience 1RM BP: 104 ± 16 kg	BPT (SM)	RE (4) (5) FP (6) 1000 Hz	15, 30, 45, 60, 75, 90 % 1RM (SSC) 15, 30, 45, 60, 75, 90 % 1RM (CO)	5
Bevan et al. [16]	47 M	Age: 25.5 ± 4.8 years BW: 101.3 ± 12.8 kg Elite rugby players	≥2 years S-P experience 1RM BP: 124 ± 19 kg	BPT (SM)	LPT (7) 500 Hz	BPT: 20, 30, 40, 50, 60 % 1RM (SSC)	5
Gorostiaga et al. [22]	15 M	Age: 31 ± 3 years BW: 95.6 ± 14.3 kg Elite handball players	≥2 years S-P experience 1RM BP: 104.8 ± 15.6 kg	BP (SM)	RE (no specified brand) 500 Hz	30, 45, 60, 70 % 1RM (CO)	4

Table 3 continued

Study	<i>n</i>	Sample description	Training status	Procedure	Measurement system	Power-load spectrum	Score
Pallares et al. [25]	17 M	Age: 25.0 ± 3.9 years BW: 81.4 ± 5.8 kg Recreationally trained	≥2 years S-P experience 1RM BP: 92.2 ± 11.9 kg	BP (SM)	LPT (3) 1000 Hz	30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100 % 1RM (CO) 0, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100 % 1RM (SSC)	5
Baker [26]	49 M	G1 = 22 Age: 24.3 ± 3.7 years BW: 93.4 ± 9.6 kg Elite rugby league players G2 = 27 Age: 18.1 ± 1.1 years BW: 91.1 ± 9.8 kg College-aged rugby league players	G1 = 22 ≥2 years S-P experience 1RM BP: 134.8 ± 15.2 kg G2 = 27 No specified time in S-P experience 1RM BP: 111 ± 15.3 kg	BPT(SM)	RE (4) 500 Hz	G1 = 22 29, 37, 44, 52, 59 % 1RM (SSC) G2 = 27 36, 45, 54, 63, 72 % 1RM (SSC)	4

(1) Unimeasure, Oregon, (2) Gymaware, Kinetic Performance Technology, Canberra, Australia, (3) T-Force System, Ergotech, Murcia, Spain, (4) Plyometric Power System (PPS), Norsearch, Lismore, Australia, (5) Omron, Japan, (6) Type 9287, Kistler, Switzerland, (7) Ballistic measurement System (BMS).

M males, *BW* body weight, *G1* Group 1, *G2* Group 2, *NCAA* National Collegiate Athletic Association, *1RM* one repetition maximum (maximum strength), *BP* bench press, *BPT* bench press throw, *SM* Smith machine, *S-P* strength-power training, *FP* force platform, *LPT* lineal position transducer, *CO* concentric only, *SSC* stretch-shortening cycle, *RE* rotary encoder, *LPT* lineal position transducer, *OE* optical encoder

overview of these studies is given in Table 3. Quality scores ranged from 4 to 5 points: 4 points—33.3 %, and 5 points—66.7 %.

3.2 Bench Press Mean and Peak Power Loading Zones

The association of zone 1 versus zone 2 mean power during the bench press exercise was investigated in five studies [19, 21–24] totaling 978 effect sizes, while bench press peak power was investigated between zone 1 and zone 2 in four studies [19, 21, 24, 25] totaling 1047 effect sizes. Mean power output during bench press exercise was greater using moderate loads (zone 2) in comparison to lighter loads (zone 1), with a pooled effect size (Hedges' *g*) of 1.19 (95 % CI 0.78–1.60, *P* = 0.001). In addition, there was no evidence of publication bias (*P* = 0.215) and large heterogeneity existed among the studies examined ($\tau^2 = 0.17$, *P* < 0.001; *I*² = 90 %) for mean power output (Figs. 2a, 3a). Peak power output during bench press exercise was also greater using moderate loads (zone 2) in comparison to lighter loads (zone 1), with a pooled effect size (Hedges' *g*) of 0.31 (95 % CI 0.03–0.60, *P* = 0.030). In addition, there was evidence of publication bias (*P* = 0.010) and large heterogeneity existed among the

studies examined ($\tau^2 = 0.06$, *P* < 0.001; *I*² = 84 %) for peak power output (Figs. 3b, 4a).

The association of zone 1 versus zone 3 mean power during the bench press exercise was investigated in five studies [19, 21–24] totaling 962 effect sizes, while bench press peak power was investigated between zone 1 and zone 3 in four studies [19, 21, 24, 25] totaling 1053 effect sizes. Mean power output during bench press exercise was greater using lighter loads (zone 1) in comparison to heavier loads (zone 3), with a pooled effect size (Hedges' *g*) of −0.25 (95 % CI −0.51–0.00, *P* = 0.054). In addition, there was no evidence of publication bias (*P* = 0.746) and large heterogeneity existed among the studies examined ($\tau^2 = 0.05$, *P* = 0.002; *I*² = 76 %) for mean power output (Figs. 2b, 3a). Peak power output during bench press exercise was also greater using lighter loads (zone 1) in comparison to heavier loads (zone 3), with a pooled effect size (Hedges' *g*) of −2.04 (95% CI −2.86 to −1.21, *P* = 0.001). In addition, there was no evidence of publication bias (*P* = 0.805) and large heterogeneity existed among the studies examined ($\tau^2 = 0.67$, *P* < 0.001; *I*² = 97 %) for peak power output (Figs. 3b, 4b).

The association of zone 2 versus zone 3 mean power during the bench press exercise was investigated in five studies [19, 21–24] totaling 1334 effect sizes, while bench

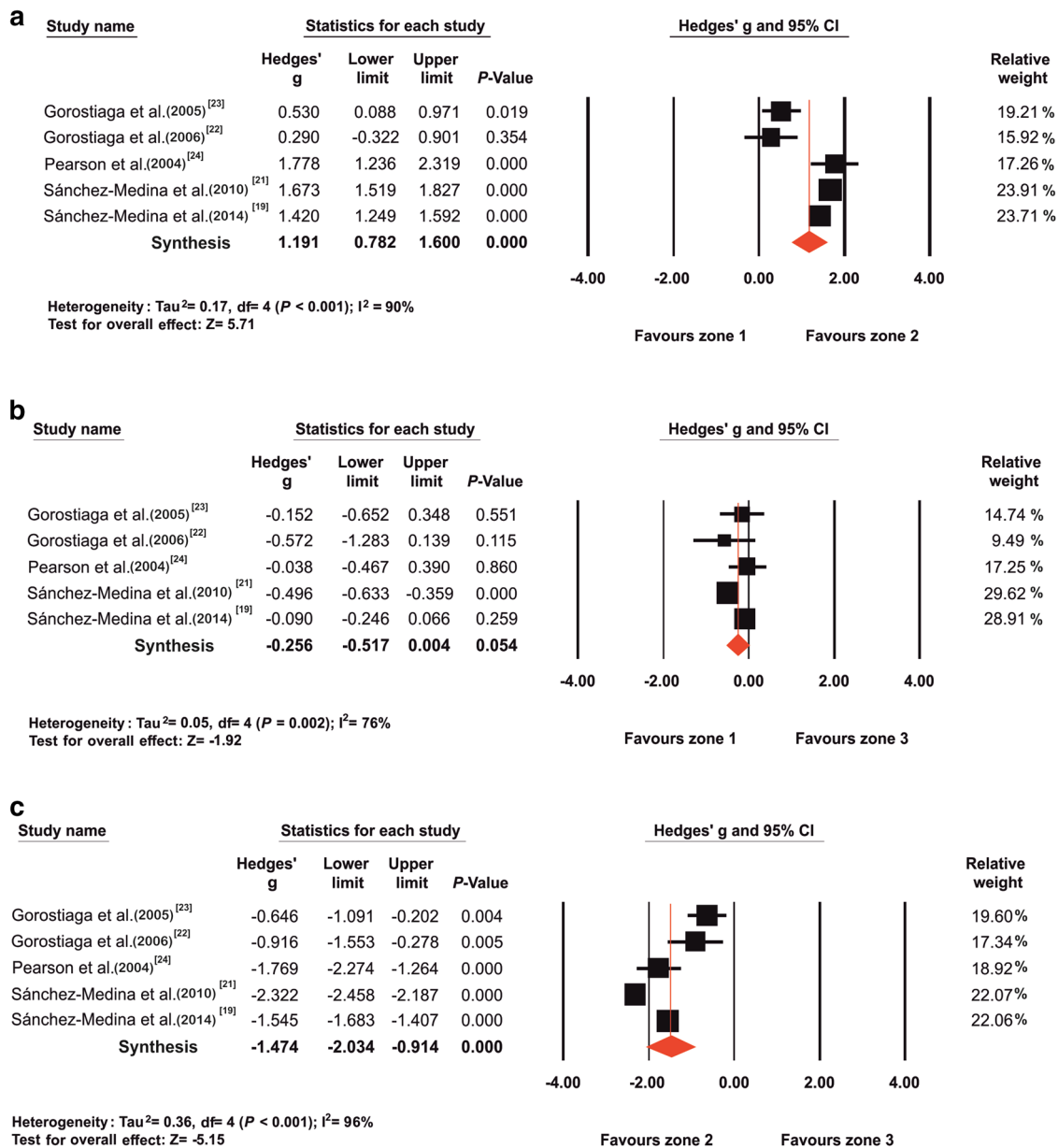


Fig. 2 Forest plots of effect sizes of bench press exercise (mean power) with **a** zone 1 compared with zone 2; **b** zone 1 compared with zone 3; and **c** zone 2 compared with zone 3. Results are expressed as Hedges' g and 95 % confidence intervals

press peak power was investigated between zone 2 and zone 3 in four studies [19, 21, 24, 25] totaling 1505 effect sizes. Mean power output during bench press exercise was greater using moderate loads (zone 2) in comparison to heavier loads (zone 3), with a pooled effect size (Hedges' g) of -1.47 (95 % CI -2.03 to -0.91 , $P = 0.001$). In addition, there was no evidence of publication bias ($P = 0.384$) and large heterogeneity existed among the studies examined ($\tau^2 = 0.36$, $P < 0.001$; $I^2 = 96\%$) for mean power output (Figs. 2c, 3a). Peak power output during bench press exercise was also greater using moderate loads (zone 2) in comparison to heavier loads (zone

3), with a pooled effect size (Hedges' g) of -2.13 (95 % CI -2.75 – 1.51 , $P = 0.001$). In addition, there was no evidence of publication bias ($P = 0.982$) and large heterogeneity existed among the studies examined ($\tau^2 = 0.37$, $P < 0.001$); $I^2 = 97\%$) for peak power output (Figs. 3b, 4c).

3.3 Bench Press Throw Mean and Peak Power Loading Zones

The association of zone 1 versus zone 2 mean power during the bench press throw exercise was investigated in three

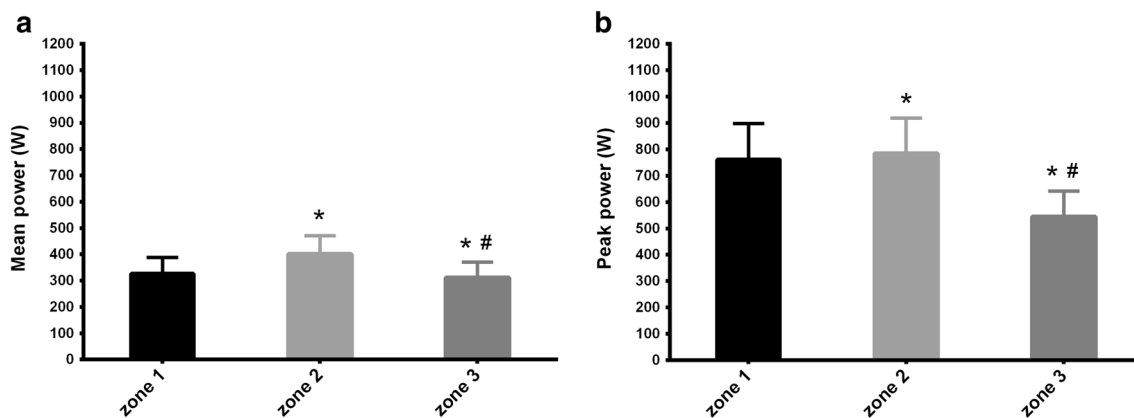


Fig. 3 Mean power (a) and peak power (b) across the loading zones in the bench press. Values are means \pm standard deviation. *Significantly different to zone 1 ($P < 0.05$); #significantly different to zone 2 ($P < 0.05$)

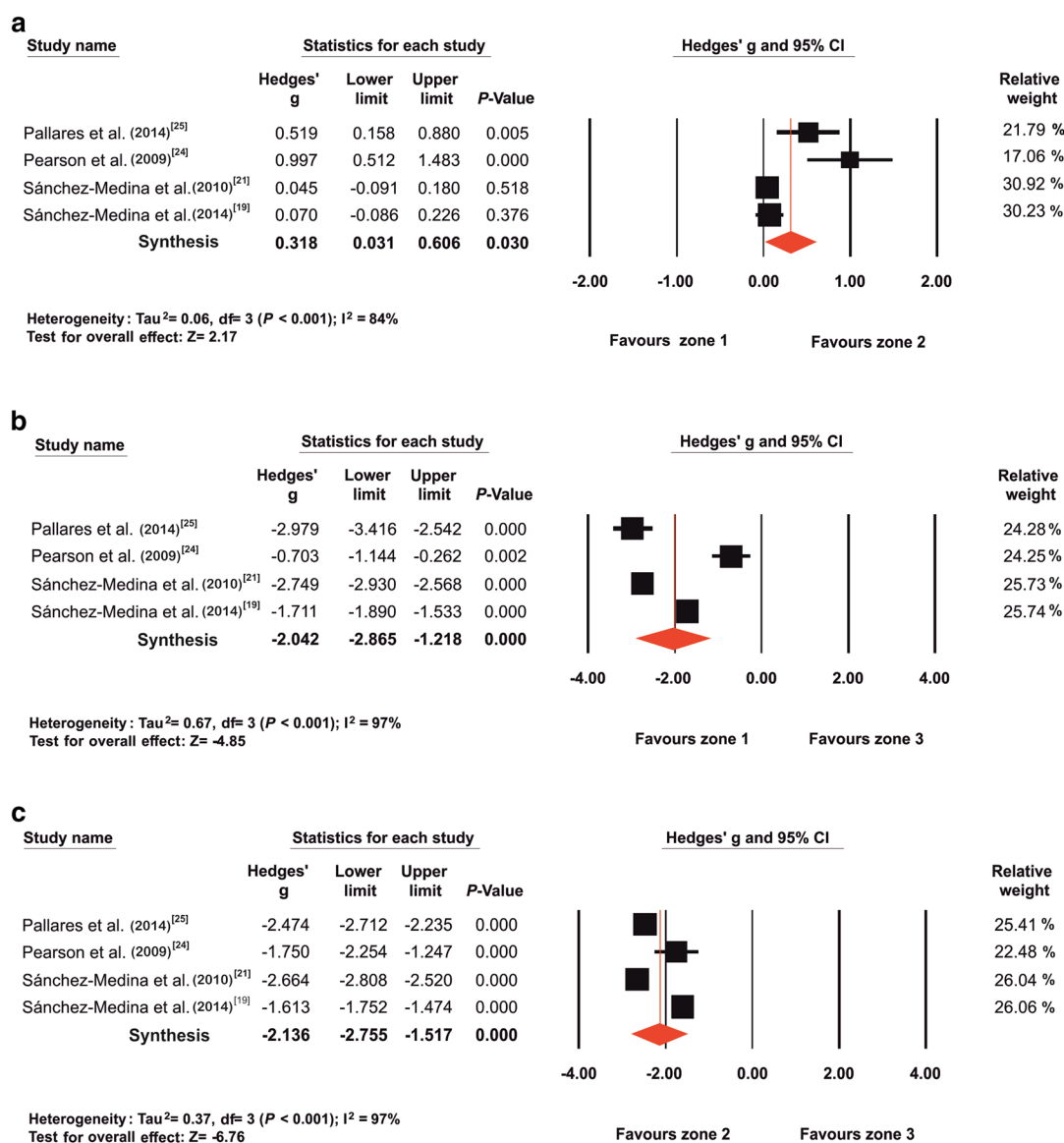


Fig. 4 Forest plots of effect sizes of bench press exercise (peak power) with a zone 1 compared with zone 2; b zone 1 compared with zone 3; and c zone 2 compared with zone 3. Results are expressed as Hedges' g and 95 % confidence intervals

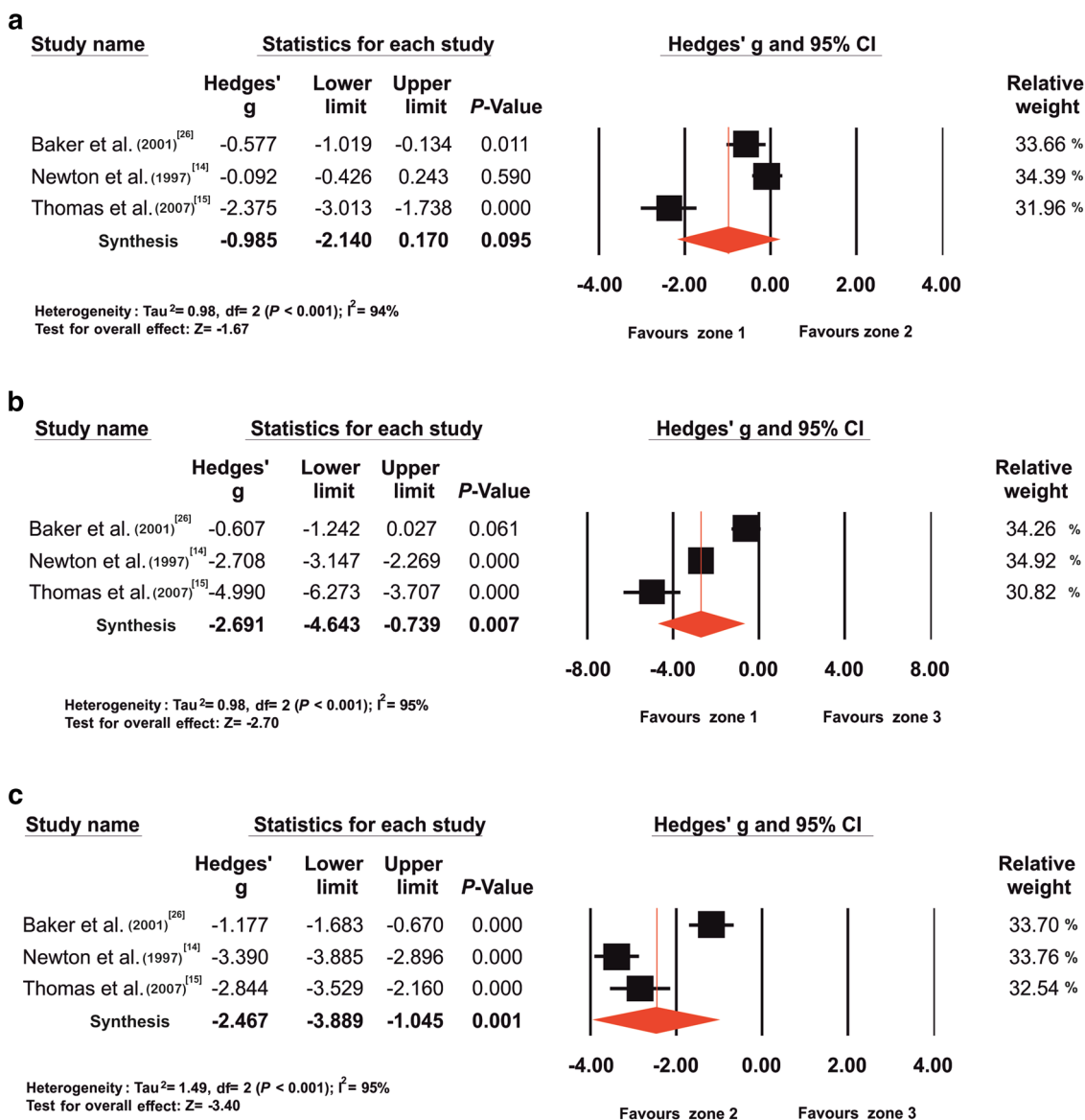


Fig. 5 Forest plots of effect sizes of bench press throw exercise (mean power) with **a** zone 1 compared with zone 2; **b** zone 1 compared with zone 3; and **c** zone 2 compared with zone 3. Results are expressed as Hedges' *g* and 95 % confidence intervals

studies [14, 15, 26] totaling 215 effect sizes, while bench press throw peak power was investigated between zone 1 and zone 2 in three studies [14, 16, 27] totaling 250 effect sizes. Mean power output during bench press throw exercise was no different using lighter loads (zone 1) and moderate loads (zone 2), with a pooled effect size (Hedges' *g*) of -0.98 (95 % CI -2.14 – 1.7 , $P = 0.095$). In addition, there was no evidence of publication bias ($P = 0.219$) and large heterogeneity existed among the studies examined ($\tau^2 = 0.98$, $P < 0.001$; $I^2 = 94\%$) for mean power output (Figs. 5a, 6a). Peak power output during bench press throw exercise was greater using lighter loads (zone 1) in comparison to moderate loads (zone 2), with a pooled effect size (Hedges' *g*) of -0.38 (95 % CI -0.76 to -0.00 ,

$P = 0.048$). In addition, there was no evidence of publication bias ($P = 0.330$) and large heterogeneity existed among the studies examined ($\tau^2 = 0.08$, $P < 0.001$; $I^2 = 77\%$) for peak power output (Figs. 6b, 7).

The association of zone 1 versus zone 3 mean power during the bench press throw exercise was investigated in three studies [14, 15, 26] totaling 115 effect sizes. Mean power output during bench press throw exercise was greater using lighter loads (zone 1) in comparison to heavier loads (zone 3), with a pooled effect size (Hedges' *g*) of -2.69 (95 % CI -4.64 to -0.73 , $P = 0.007$). In addition, there was no evidence of publication bias ($P = 0.850$) and large heterogeneity existed among the studies examined ($\tau^2 = 0.98$, $P < 0.001$; $I^2 = 95\%$) for

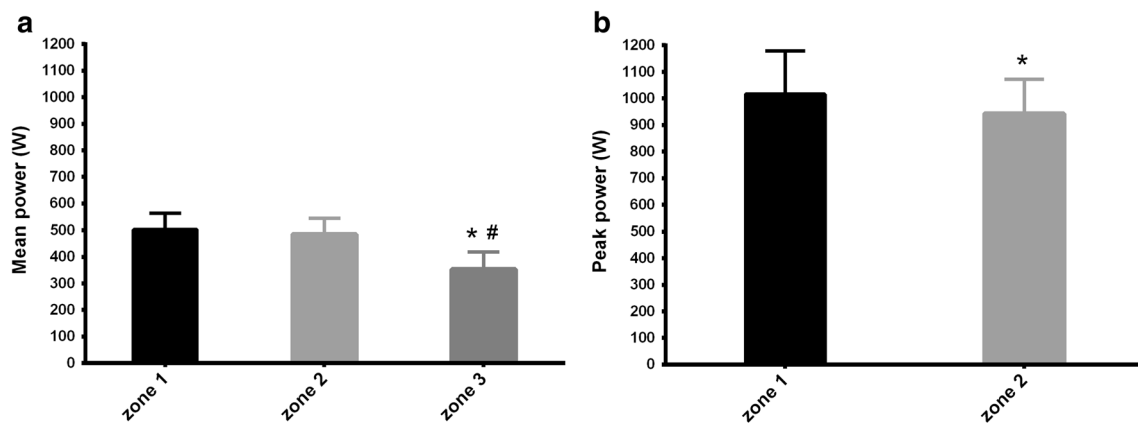


Fig. 6 Mean power (a) and peak power (b) across the loading zones in the bench press throw. Values are means \pm standard deviation. *Significantly different to zone 1 ($P < 0.05$); #significantly different to zone 2 ($P < 0.05$)

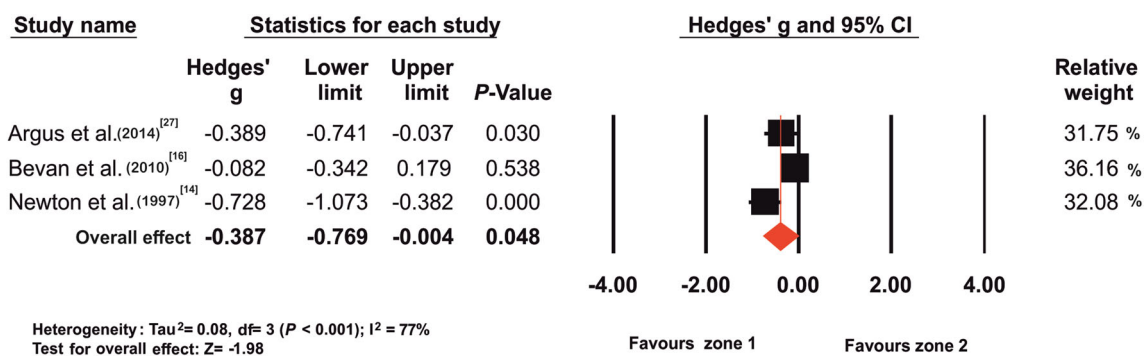


Fig. 7 Forest plots of effect sizes of bench press throw exercise (peak power) with a zone 1 compared with zone 2

mean power output (Figs. 5b, 6a). There were not enough studies (≤ 2 studies) to allow a meaningful comparison of zone 1 versus zone 3 during bench press throw exercise for peak power.

The association of zone 2 versus zone 3 mean power during the bench press throw exercise was investigated in three studies [14, 15, 26] totaling 221 effect sizes. Mean power output during bench press throw exercise was greater using moderate loads (zone 2) in comparison to heavier loads (zone 3), with a pooled effect size (Hedges' g) of -2.46 (95 % CI -3.88 to -1.04 , $P = 0.001$). In addition, there was no evidence of publication bias ($P = 0.890$) and large heterogeneity existed among the studies examined ($\tau^2 = 1.49$, $P < 0.001$; $I^2 = 95\%$) for mean power output (Figs. 5c, 6a). There were not enough studies (≤ 2 studies) to allow a meaningful comparison of zone 2 versus zone 3 during bench press throw exercise for peak power.

4 Discussion

The results of the current meta-analysis provide additional evidence that optimal loads for mean and peak power development are exercise-specific [10, 28]. Figures 3 and 6

display the optimal zones to maximize power production during the bench press and bench press throw, respectively. Although the examined exercises possess many biomechanical similarities, the intent of the movement may alter the force-velocity profile of each exercise [14]. For example, previous research indicated that the bench press throw may produce greater forces compared to the bench press regardless of the load examined, but may also spend a greater proportion of the concentric movement at a higher intensity of effort compared to the bench press [29]. Due to the unique characteristics of the bench press and bench press throw, it is clear that a single relative intensity cannot be broadly prescribed to each exercise as the optimal load for mean or peak power development.

Information regarding the differences in optimal load between the bench press and bench press throw may be of practical importance. For example, each exercise may be implemented in order to train separate aspects of the force-velocity curve. The bench press at moderate loads (30–70 % 1RM) elicited greater mean and peak power compared to lighter ($\leq 30\%$ 1RM) and heavier loads ($\geq 70\%$ 1RM). In contrast, lighter loads produced the greatest mean and peak power magnitudes during the bench press throw exercise. The use of lighter loads may

favor the recruitment of higher end motor units, increase rate coding, and synchronize active motor units, which may manipulate the early phases of rate of force development [30]. In contrast, exercises that use heavier loads performed with maximal intent may produce adaptations in both the early and late phases due to greater forces and longer contraction times through further adaptations in neural drive and peripheral muscle properties [31].

Previous literature has suggested that a mixed methods approach that includes a combination of heavy and light loads may produce superior adaptations to the force-velocity curve [2]. Therefore, the use of different exercises that possess various optimal loads may aid in the full development of the power potential of each athlete. Moreover, research that examines multiple exercises and loads may assist practitioners in their programming decisions for the development of the entire force-velocity curve. An interesting finding of this meta-analysis is the lower external mechanical power exhibited by the bench press exercise, compared to the bench press throw, during all loading conditions. The bench press serves as a foundational exercise that may produce increased levels of strength that may be exploited in subsequent training phases for enhanced rate of force development and peak power. Due to the nature of the exercise, the bench press may be best implemented during phases of training where the primary goals are to increase muscular strength and, by extension, force production. Programming in such a manner may allow the bench press to serve as a transitional exercise to other movements that are more ballistic in nature, such as the bench press throw [32]. In contrast, the bench press throw may best serve the practitioner to increase the rate of force development, power production, and velocity of their athletes.

Limitations to the current meta-analysis should be addressed. First, the findings should be interpreted bearing in mind that the effect of load on mean and peak power was assessed using cross-sectional studies compared to the results from training intervention studies. Because previous literature indicated that different physical characteristics [12, 32, 33] and training modes may influence the power production characteristics of an individual [30, 31, 34, 35], it is likely that the load that maximizes mean and peak power may change following training. A second limitation may be the number and heterogeneity of studies included within the current meta-analysis. There is a large disparity between the amount of lower and upper body scientific literature that has examined the effect of load on power production and, thus, a similar magnitude of comparisons could not be made using the extant upper body literature. Although a recent meta-analysis examined the effect of load on lower body power production during different exercises [10], no extant literature has performed a similar

analysis with upper body exercises, making the current meta-analysis the first of its kind. While the above limitations may exist, the information gathered from the current meta-analysis may benefit strength and conditioning practitioners from an exercise prescription standpoint, but may also serve as a hypothesis generating analysis for future research.

5 Conclusions

The current meta-analysis of the included studies provides evidence for exercise-specific optimal load ranges for mean and peak power production. This meta-analysis also provides valuable information for strength and conditioning professionals regarding specific load prescription during training. Zone 2 (30–70 % 1RM) appears to provide the optimal loading range for mean and peak power production during the bench press, whereas zone 1 (≤ 30 % 1RM) appears to provide the optimal loading range for mean and peak power production during the bench press throw. Optimal load ranges for mean and peak power production are exercise specific, suggesting that future research evaluating different exercises is warranted.

Compliance with Ethical Standards

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