Is there a relationship between the overhead press and split jerk maximum performance? Influence of sex

Running Title: The relationship between the overhead press and split jerk performance

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Abstract

The aims of this study were to (I) determine the differences and relationship between the overhead press and split jerk performance in athletes involved in weightlifting training, and (II) explore the magnitude of these differences in one-repetition maximum (1RM) performances between sexes. Sixty-one men (age: 30.4 ± 6.7 years; height: 1.8 ± 0.5 m; body mass 82.5 ± 8.5 kg; weightlifting training experience: 3.7 ± 3.5 yrs) and 21 women (age: 29.5 ± 5.2 yrs; height: 1.7 ± 0.5 m; body mass: 62.6 ± 5.7 kg; weightlifting training experience: 3.0 ± 1.5 yrs) participated. The 1RM performance of the overhead press and split jerk were assessed for all participants, with the overhead press assessed on two occasions to determine between-session reliability. The intraclass correlation coefficients (ICC) and 95% confidence intervals showed a high reliability for the overhead press ICC = 0.98 (0.97 – 0.99). A very strong correlation and significant differences were found between the overhead press and split jerk 1RM performances for all participants (r = 0.90 [0.93 – 0.85], 60.2 ± 18.3 kg, 95.7 ± 29.3 kg, $p \leq 0.001$). Men demonstrated stronger correlations between the overhead press and split jerk 1RM performances (r = 0.83 [0.73-0.90], $p \leq 0.001$) compared with women (r = 0.56 [0.17-0.80], $p = 0.008$). These results provide evidence that 1RM performance of the overhead press and split jerk performance are highly related, highlighting the importance of upper-limb strength in the split jerk maximum performance.

Key words: weightlifting, strength, one repetition maximum, correlations, resistance-training.

Introduction

Muscular strength is considered a cornerstone of dynamic athletic performance. Greater muscular strength in athletes has been associated with enhanced force-time and power development characteristics, which may impact both general (i.e. jumping, sprinting, changing of direction) and specific sport performance (i.e. powerlifting, weightlifting) [1]. Therefore, the assessment of maximum strength is of great importance to researchers and practitioners to monitor changes and guide aspects of programming, including load prescription to enhance force-time characteristics, and consequently, athletic development [2].

Maximum strength assessment appears to be highly task-specific and very sensitive to factors such as contraction type (i.e. isometric, isotonic, isokinetic), movement pattern, range of motion, testing methodology and protocol-related issues (i.e. warm-up strategy, motivation and loading scheme) [2,3]. The assessment of maximum strength with the one-repetition maximum (1RM) test seems to be the preferred method employed by strength and conditioning coaches to best capture the dynamic strength capacity of athletes [2,3]. Furthermore, the 1RM test is relatively simple, requires relatively inexpensive equipment, and can be performed using the same exercises as those undertaken during regular training, thereby assisting with the prescription of load for the subsequent training phase [2].

Maximum dynamic strength is defined as the maximum amount of force that an athlete can produce against an external load [4]. The external load is commonly influenced by an external mass (i.e. artefact, implement, barbell) and the individual's own body mass, which is known as the system of mass. Maximum dynamic strength is an integral part of most sports (e.g. throwing events, collision sports, contact sports, wrestling) especially in strength/power sports, such as weightlifting [5]. Weightlifting is a sport where two lifts, the snatch and the clean and jerk (C&J), are contested. Weightlifters are required to generate high peak forces, rates of force development and impulses within times governed by technical constraints in order to lift more load than their opponents [5]. Although these exercises involve the whole-body in a complex and ballistic sequence of high intensity muscular actions, the performance capabilities of competitive weightlifters seem to primarily depend upon lower-limb strength and power [5,6].

Maximum dynamic strength of the lower limbs has previously been found to be related to weightlifting performance. For example, Stone et al. [7] reported that maximum dynamic strength, measured by the 1RM back squat test, was almost perfectly correlated with snatch and clean performance in well-trained male weightlifters ($r = 0.94$, $r = 0.95$, respectively), with these correlations lower for women ($r = 0.79$, $r = 0.86$, respectively). In addition, there were significant differences between men and women for the maximum strength measured by the 1RM back squat (31% difference), snatch (38%) and C&J (33%). Similarly, Carlock et al. [8] also reported strong correlations between the 1RM back squat and snatch and C&J performance in elite and academy weightlifters ($r = 0.94$, $r = 0.95$, respectively); however, correlations were lower for women (snatch: $r = 0.79$, C&J: $r = 0.86$) compared with men (snatch: $r = 0.93$, C&J: $r = 0.95$), independent of their training status. Furthermore, it has been described that weightlifting top performers present higher levels of maximum strength than their weaker counterparts [5]. These findings highlight a strong relationship between the maximum strength of the lower limbs, measured by the 1RM back squat, and weightlifting performance, though this relationship seems to be weaker for women.

Researchers have recently suggested the use of weightlifting overhead pressing derivatives to improve weightlifting performance by specifically, improving the jerk phase of the C&J [9]. These recommendations are based upon the belief that the jerk is a complex and difficult skill to master in the modern era of weightlifting. This belief is often based upon the high incidence of failure registered in weightlifters during the jerk during competitions [9]. The C&J has been strongly correlated to maximum lower-limb strength by numerous research [7,8,10]. In contrast, to our knowledge, researchers have not focused on the relationship between the upper limb's maximum strength and weightlifting performance, likely because there is no marked pressing of the barbell with the upper limbs during weightlifting movements in competition. Additionally, to the authors' knowledge there is no published information about the relationship between a lifter's 1RM overhead press and their overall jerk performance. Therefore, the aim of this study was to determine the differences and relationships between the overhead press and jerk performance in athletes involved in weightlifting training. A further aim of this study was to explore the magnitude of these differences between males and females. It was hypothesized that there would be a strong correlation between the overhead press and jerk. It was also hypothesized that men would outperform women and exhibit stronger correlations than women in line with previous results [11].

Methods

Participants

Sixty-one men (age: 30.4 ± 6.7 years; height: 1.8 ± 0.5 m; body mass [BM]: 82.5 ± 8.5 kg; weightlifting training experience: 3.7 ± 3.5 yrs) and 21 women (age: 29.5 ± 5.2 yrs; height: 1.7 ± 0.5 m; BM: 62.6 ± 5.7 kg; weightlifting training experience: 3.0 ± 1.5 yrs) volunteered to participate. Participants were amateur competitors in regional and national tournaments in CrossFit® and weightlifting. Furthermore, they were required to have ≥6 months of weightlifting experience, performed regularly (≥3 x week). Participants had previously performed 1RM testing for a variety of exercises. All participants provided written informed consent prior to participation, with ethical approval provided by the institutional review board. The study conformed to the principles of World Medical Association´s Declaration of Helsinki.

Study design

A cross-sectional study design was used to determine the differences and relationship between 1RM performance of the upper-limbs maximum dynamic strength (measured by the 1RM test of the overhead press) and the jerk in males and females. Ratio scaled 1RM (1RM/body mass [BM]) values were used for the comparison between men and women, as previously suggested [11], due to the large differences in BM reported between sexes (men: 82.5 ± 8.5 kg, women: 62.6 ± 5.7 kg).

The 1RM of the overhead press was evaluated on two occasions to determine between-session reliability. The jerk was evaluated using a standardized protocol previously validated for overhead pressing exercises (Intraclass correlation coefficient [ICC] = 0.99 [12]. All tests were conducted on separate days with ≥72h of rest between assessments, over maximum duration of 2 weeks. Verbal encouragement was provided throughout all maximal testing conditions. Participants were asked to replicate their fluid and food intake 24 hours before the day of testing, to avoid strenuous exercise for 48 hours before testing, and to maintain any existing supplementation regimen throughout the duration of the study.

Testing Procedures

Participants completed a warm up protocol for a single 1RM assessment method previously described by Soriano et al. [12]. Briefly, the warm-up consisted of dynamic activation and two sets of ten repetitions of exercise-specific drills (air squats, front squats at ¼, ½, and full depth, overhead press, push press, push jerk and split jerk, lifting the barbell mass only). Subsequently, one set of 5 submaximal (50-60% of self-estimated 1RM) repetitions for the exercise required (the overhead press or split jerk), and after 5 minutes of rest another set of 3 submaximal (70-85% of self-estimated 1RM) repetitions for each exercise. After the warm-up, participants rested for 5 minutes before the start of the single 1RM assessment method. Technical aspects of the exercises (the overhead press and split jerk) have been well defined elsewhere [9,12]. The guidelines previously provided were strictly followed to avoid confusion and set appropriate technique standards. Briefly, in the overhead press, (also known as the military press and barbell shoulder press) the lifter begins standing with the barbell resting in the front rack position using a prone grip of medium width with the elbows oriented downward. Then, the barbell must be pressed to an overhead position through flexion of the shoulders and full extension of the elbows, while the trunk and the legs provide stability. Note that the legs must not be involved as prime movers during the propulsion phase of the lift. For the split jerk, participants perform a shallow countermovement followed by fully extending the hips, knees, and ankles, accelerating the barbell upward then subsequently dropping under the barbell, to catch the bar in a split stance, with shoulders flexed and elbows fully extended overhead [12]. After a successful overhead press, participants were allowed to return the barbell to the front rack position, performing a shallow dip to absorb the barbell's impact. On the other hand, after the recovery phase of the jerk, participants must hold the barbell overhead for a couple of seconds, then participants were instructed to drop the barbell forward. Two certified national weightlifting coaches supervised and verified the technique of the lifts.

The 1RM assessment started from a near-maximal load (95% of self-estimated 1RM) and each successful attempt was followed by an increment of the load of 2.5-5.0% until the 1RM was reached, following NSCA guidelines [13]. Participants rested from 3 to 5 minutes between attempts for both exercises. The barbell was taken out of power racks before starting each attempt to minimize the fatigue associated with the performance of the clean, which precedes the split jerk in competitions [12]. All testing sessions were performed using standardized Olympic barbells and plates (Powerkan Sports Equipment, Valladolid, Spain), lifting platforms, power racks and spring-loaded collars. A 20 kg Olympic barbell was used for men, while a 15 kg Olympic barbell was used for women.

Statistical Analyses

To determine between-session reliability for the overhead press 1RM performance, ICC's (model 3.1) and associated 95% confidence intervals (CI) were calculated and interpreted based on the ICC lower bound 95% CI, as previously recommended [14]. Percentage coefficient of variation (%CV) and associated 95% CI were also calculated and a value of < 15% CV was used as a criterion for the minimum acceptable reliability [15]. Standard error of measurement (SEM) and smallest detectable difference (SDD) were also calculated for men and women to establish random error scores between testing sessions following the guidelines provided [16]. SEM was calculated using the formula: (SD[pooled] $\times \sqrt{1 - \text{ICC}}$), whereas SDD was calculated from the formula: (1.96 x [$\sqrt{2}$]) $\times$ SEM.

Pearson's correlation coefficients with 95% CI and coefficient of determination were also calculated between the overhead press and jerk to determine relationships between 1RM performances for men and women. An *a priori* alpha level was set at $p \leq 0.05$. The Pearson's correlation coefficients were interpreted based on the recommendations of Schober et al. [17] where ≤ 0.10 represents negligible correlation, 0.10-0.39 weak correlation, 0.40-0.69 moderate correlation, 0.70 to 0.89 strong correlation, and ≥ 0.9 very strong correlation. Furthermore, an r-z transformation was performed to compare the strengths of correlations between men and women [18].

Normality of the subject's characteristics (i.e. age, height, BM and weightlifting experience) was tested using Shapiro Wilk's test. The t-test for independent samples was used to test between-group differences. If normality was violated, the Mann-Whitney U's test for independent samples was used to test between-group differences. Hedges' *g* effect sizes (ES) were used and interpreted following previous guidelines: $g \leq 0.2$ = "trivial", $g > 0.2 \leq 0.6$ = "small", $g > 0.6 \leq 1.2$ = "moderate", $g > 1.2 \leq 2.0$ = "large", $g > 2.0 \leq 4$ = "very large", and $g > 4.0$ = "extremely large" [19].

Shapiro-Wilk's and Levene's tests were used to determine the distribution and the homogeneity of variances of the 1RM performances and 1RM/BM, respectively. An *a priori* alpha level was set at $p \leq 0.05$. A t-test for paired samples was used to determine the differences between the 1RM performances (overhead press vs. split jerk) for the whole sample and for men and women, separately. An independent samples t-test was used to determine the differences of the 1RM/BM performances of the overhead press and split jerk between men and women. When normality or the homogeneity of variances was violated ($p \leq 0.05$), Mann-Whitney U's test was used. Hedge's *g* ES was used and interpreted as cited in the previous paragraph. Furthermore, univariate dot plots of the 1RM performance of the overhead press and split jerk for men and women have been presented for a more complete presentation of the data [20,21]. In addition, the overhead press performance was normalized to the 1RM of the split jerk for practical applications.

Results

Overhead press 1RM for the whole sample was highly reliable (ICC = 0.98 [0.97 – 0.99], CV = 4% [3.42 – 4.98]), along with a low measurement error (SEM = 2.55 kg [4%], SDD = 7.07 kg [12%]). Overhead press 1RM reliability was also high for men (ICC = 0.98 [0.97 – 0.99], CV = 3% [2.92 – 4.18]) and women (ICC = 0.92 [0.82 – 0.97, CV = 4% [3.06 – 5.77]), with a low measurement error for men (SEM = 1.91 kg [3%], SDD = 5.28 kg [8%]) and women (SEM = 1.40 kg [4%], SDD = 3.90 kg [11%]).

A very strong and significant correlation was found between the overhead press and split jerk 1RM for the whole sample (r = 0.90 [0.93 – 0.85], $p \leq 0.001$). Men showed strong and significant correlations between the overhead press and split jerk 1RM (r = 0.83 [0.73-0.90], $p \leq 0.001$), while women demonstrated moderate and significant correlations (r = 0.562 [0.17-0.80], $p = 0.008$) (**Figure 1**). The r-z transformation demonstrated that there was a significant difference between men and women (z = 2.1, $p < 0.05$).

[Figure 1]

Shapiro-Wilk's test of normality revealed that participants' age and BM were normally distributed for both groups ($p > 0.05$). However, normality of men's height ($p = 0.04$) and weightlifting experience ($p \leq 0.001$) was not confirmed. Results of an independent samples t-test revealed no significant differences in age between men and women (p = 0.6; ES = 0.2 [trivial]). Men demonstrated a significantly greater BM in comparison to women ($p \leq 0.001$; ES = 2.8 [very large]). The results of the Mann-Whitney U test revealed that men were significantly taller compared to the women ($p \leq 0.001$, ES = 2.5 [very large]). There were no statistically significant differences in weightlifting training experiences between groups (p = 0.4; ES = 0.3 [small]) (**Table 1**).

Table 1. Descriptive characteristics of the groups

Group	Sample size (n)	Age (years)	Height (cm)	Body mass (kg)	WL training experience (years)
Men [range]	61	30.4 ± 6.7 [18–43]	179.0 ± 4.9 [170–193]	82.5 ± 8.5 [72–102]	3.7 ± 3.5 [0.5–25]
Women [range]	21	29.5 ± 5.2 [20–42]	167.0 ± 4.6* [158–175]	62.6 ± 5.7* [32–72]	3.0 ± 1.5 [1–5.5]
ES [Interpretation]		0.2 Trivial	2.5 Very large	2.8 Very large	0.3 Small

WL weightlifting, 1RM one repetition maximum, PP push press, PJ push jerk, SJ split jerk.
*significantly (p<0.001) lower than the male's group

The results of the paired samples t-test revealed significant differences between the overhead press and split jerk (60.2 ± 18.3 kg, 95.7 ± 29.3 kg, respectively; $p \leq 0.001$) with large ES (1.5) for the whole sample. Specifically, men (overhead press = 68.3 ± 13.7 kg, split jerk = 107.2 ± 23.6 kg; $p \leq 0.001$, ES = 2.0 [large]) and women (overhead press = 36.8 ± 5.1 kg, split jerk = 62.3 ± 15.0 kg; $p \leq 0.001$, ES = 2.2 [very large]) demonstrated significantly lower performance in the overhead press compared to the split jerk performance (**Figure 2**). Similarly, the results of the Mann-Whitney U test showed that when ratio scaled women still demonstrated significantly lower overhead press performance ($p \leq 0.001$, ES = 1.9) compared to men. The results of the independent samples t-test also revealed that women demonstrated significantly lower ratio scaled split jerk performance ($p < 0.001$, ES = 1.3) compared to men (**Figure 3**).

[Figure 2]

[Figure 3]

Discussion

The main findings of this study were that a) there was a strong relationship between overhead press and split jerk performance, b) participants lifted heavier loads in the split jerk compared with the overhead press, and c) men lifted heavier loads across the two exercises compared to women, even when ratio scaled, as hypothesized. A novel finding of this study was that the magnitude of the differences between lifts do not differ between men and women. In contrast, the magnitude of correlations for the 1RM performance between the overhead press and jerk were higher for men than for women, as hypothesized. These findings are important for strength and conditioning coaches because they illustrate the extent that maximum strength of the upper limbs is related to performance in the split jerk.

In our study, upper limb strength was measured by the overhead press instead of the bench press, as the latter has been commonly applied to other sports [2]. This choice was based on the notion that strength adaptations are highly task-specific [2], and the overhead press seems to be more applicable to split jerk performance than bench press due to the development of force through a closed kinetic chain, while the trunk and lower-limbs provide stability for the development of the lift [9]. Researchers have further suggested that vector-oriented force application may play a key role in the resulting adaptations [22].

Therefore, the overhead press, a vertically oriented movement has been suggested as a good predictor of split jerk performance [9]. However, researchers and practitioners may argue that the split jerk is not a strictly pressing motion. Nonetheless, it is well-known from practical experience that the jerk requires strength, mobility and stability of the upper-limbs; especially, in the lockout position [9,23,24]. In this study, a very strong correlation was found between the overhead press and split jerk performance (r = 0.90) for the whole sample, with a coefficient of determination [R^2] of 0.81, suggesting that overhead press performance can explain 81% of split jerk performance. Based upon these findings the maximum strength of the upper limbs seems to exert a large impact on split jerk performance.

The split jerk is a unique movement where the largest loads are lifted to an overhead position. Furthermore, studies that have analyzed split jerk performance' kinetic parameters have shown high values of power development (2500 – 6953 W for peak power, 2690 – 4321 W for mean power), which is simply due to the fact that heavy loads are lifted at relatively high speed [25]. In our study, participants performed better in the split jerk than the overhead press, where the split jerk to overhead press ratio represents 64% (**Figure 2**). These differences are due to the fact that while the overhead press involves strictly the upper-limbs' maximum dynamic strength to lift the load, the split jerk involves an impulsive triple extension of the hips, knees and ankles (plantar flexion) to accelerate the barbell overhead [9]. These findings are in an agreement with previous research suggesting that the performance capabilities of weightlifting seem to primarily depend upon lower-limb strength and power, and therefore, the differences between the overhead press and split jerk performance [5,6].

To the author's knowledge, this is the first study to compare the differences between the overhead press and split jerk performance between men and women. For this comparison, a ratio scaling of the 1RM performance was used to diminish the differences in BM between men and women, as previously suggested [11,26]. In this study, men had a higher relative 1RM than women for both the overhead press and split jerk (**Figure 3**). Although this finding has not been previously investigated, these results are in line with prior research on other weightlifting overhead pressing derivatives, where men demonstrated greater absolute and relative 1RM performances for the push press, push jerk and split jerk, compared to women [11].

A novel finding of this study was that the differences between the overhead press and split jerk 1RM performances did not differ between men and women (**Figure 2**). However, the relationships between the overhead press and split jerk performance differed, with men showing stronger correlations than women (r = 0.83, r = 0.56, respectively) (**Figure 1**). The stronger relationships between the overhead press and split jerk performance in men in comparison to women may be attributable to a higher strength of the upper limbs (**Figure 3**), where men could tend more easily to rely on their upper-limb's strength to execute the split jerk. However, in the case of women, as lower strength of their upper limbs have been reported (**Figure 3**), a greater relevance of the individual technical mastery during the jerk is expected [11], in addition to the developing pressing strength.

A potential limitation in the generalizability of these findings may be the combination of sports disciplines (CrossFit® and weightlifting) as there is a strong influence of the specificity principle in the 1RM performance during the split jerk [11,27]. Specifically, weightlifters have a higher technical mastery and are technically more efficient justified by a higher volume of repetitions. In contrast, CrossFit® athletes may rely on their upper-limb strength more to supplement technical deficiencies during the jerk [11,27]. However, the coefficient of determination between the overhead press and split jerk performance for the 54 CrossFit® athletes and 28 weightlifters of this study was quite similar (R^2 = 0.85, R^2 = 0.83, respectively). Finally, a combination of the upper limb and lower limb maximum strength, measured by the overhead press and back squat, respectively, could offer a more complete picture of the strength needs related to weightlifting performance. However, "*correlation does not imply causation*" [28], then, these findings should be supported by research implementing training programs aiming to improve the upper-limb maximum strength and its subsequent effect on weightlifting performance.

Taken collectively, the results of the present study provide evidence that the maximum strength of the upper limbs is related to split jerk performance. In fact, the 1RM performance of the overhead press explains 81% of the variance in jerk performance, with a jerk to overhead press ratio of more than 60%. Therefore, to optimize split jerk performance, it is important that pressing motions such as the overhead press, push press or other variations are included as part of the athletes training program. Therefore, coaches may prescribe training loads focusing on increasing maximum strength of the upper limbs while working on split jerk technique, especially in male population. These findings are in line with prior research which suggested that a strong overhead press could benefit jerk performance in elite weightlifters [23,24].

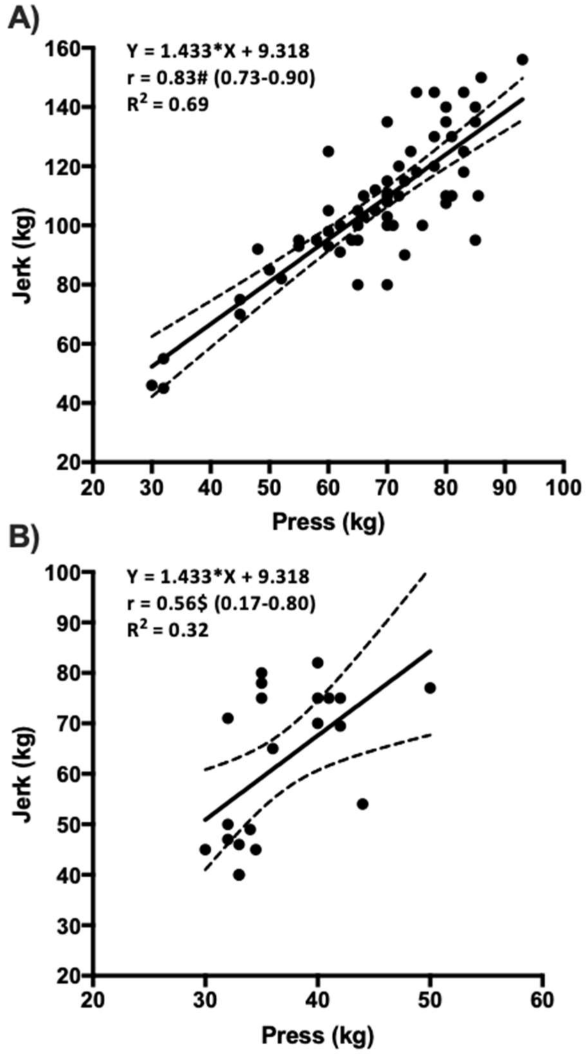

Figure 1. Relationships of the one repetition maximum (1RM) performance between the overhead press and split jerk in men (A, upper panel) and women (B, lower panel). (mean ± SD). # $p < 0.001$, \$ $p < 0.008$. The regression model, Pearson's correlation coefficient (r) with 95% confidence interval, and coefficient of determination (R^2) are depicted.

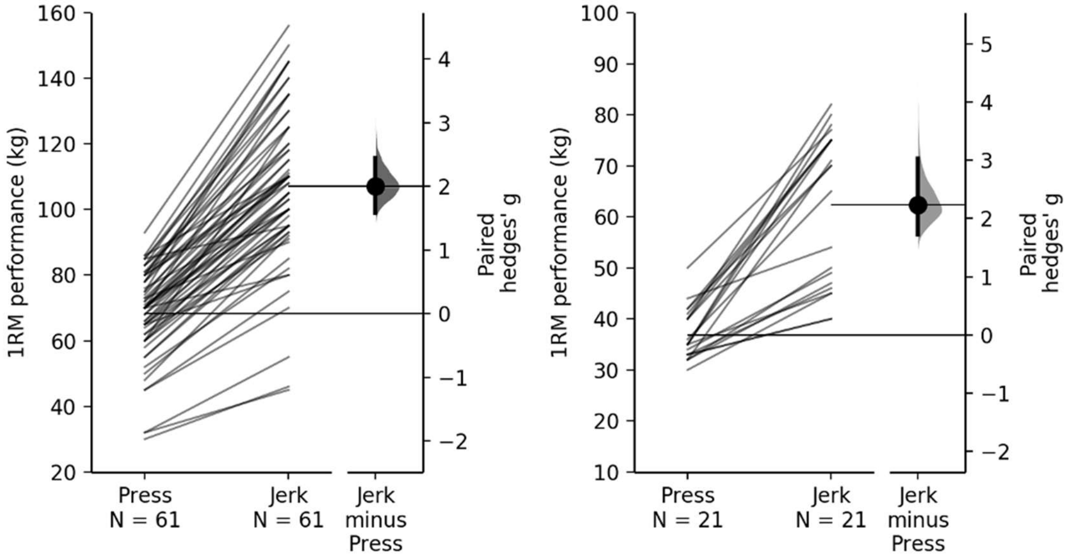

Figure 2. Individual comparisons between the 1RM performance of the overhead press and split jerk for men (left panel) and women (right panel). The paired Hedges' *g* and associated 95%CI between the overhead press and split jerk is 2.0 (1.6 – 2.2) for men (left panel) and 2.2 (1.7 – 3.0) for women (right panel). The results of the t-tests demonstrated significantly greater ($p < 0.001$) performance in the split jerk compared to the overhead press. 1RM = one repetition maximum.

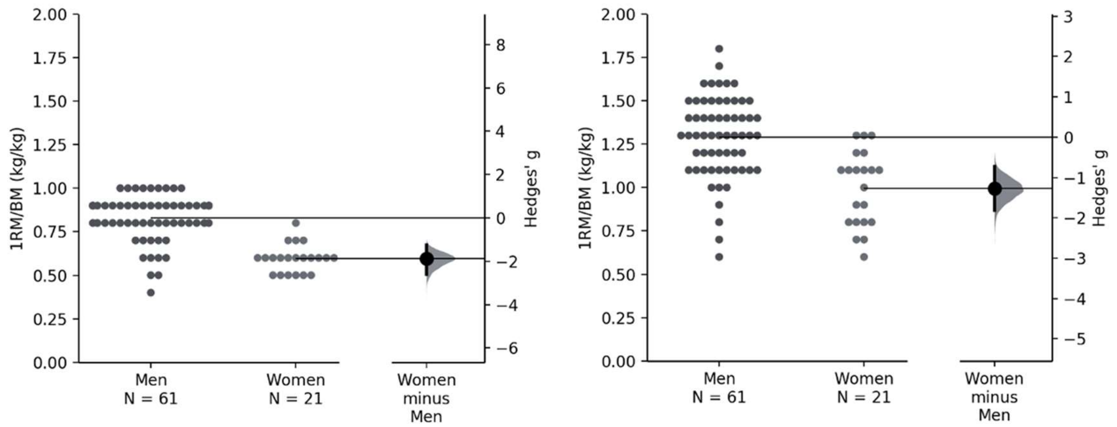

Figure 3. Comparison of relative 1RM performances between men and women (univariate dot plots) for the overhead press (left panel) and split jerk (right panel). The paired Hedges' *g* and associated 95%CI between the overhead press and split jerk is -1.9 (-2.6 – -1.2) for the overhead press (left panel) and -1.3 (-1.8 – -0.7) for split jerk (right panel). The results of the t-tests revealed a significantly greater ratio scaled overhead press and split jerk performance ($p < 0.001$) in men compared to women. 1RM = one repetition maximum. 1RM = one repetition maximum. BM = body mass.

Declaration of Conflict of Interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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References

1. Suchomel, TJ, Nimphius, S, and Stone, MH. The importance of muscular strength in athletic performance. *Sport Med* 2016; 46: 1419-1449.
2. McMaster, DT, Gill, N, Cronin, J, and McGuigan, M. A brief review of strength and ballistic assessment methodologies in sport. *Sport Med* 2014; 44: 603-623.
3. Abernethy, P, Wilson, G, and Logan, P. Strength and power assessment: issues, controversies and challenges. *Sport Med* 1995; 19: 401-417.
4. Stone, MH, Moir, G, Glaister, M, and Sanders, R. How much strength is necessary? *Phys Ther Sport* 2002; 3: 88-96.
5. Stone, MH, Pierce, KC, Sands, WA, and Stone, ME. Weightlifting: a brief overview. *Strength Cond J* 2006; 28: 50-66.
6. Garhammer, J. A review of power output studies of Olympic and powerlifting: Methodology, performance prediction, and evaluation tests. *J Strength Cond Res* 1993; 7: 76-89.
7. Stone, MH, Sands, WA, Pierce, KC, Carlock, J, Cardinale, M, and Newton, RU. Relationship of maximum strength to weightlifting performance. Med Sci Sports Exerc 37(6): 1037-1043, 2005.
8. Carlock, JM, Smith, SL, Hartman, MJ, Morris, RT, Ciroslan, DA, Pierce, KC, et al. The relationship between vertical jump power estimates and weightlifting ability: A field-test approach. *J Strength Cond Res* 2004; 18: 534-539.
9. Soriano, M, Suchomel, T, and Comfort, P. Weightlifting overhead pressing derivatives: a review of the literature. *Sport Med* 2019; 49: 867–885.
10. Lucero, RAJ, Fry, AC, LeRoux, CD, and Hermes, MJ. Relationships between barbell squat strength and weightlifting performance. *Int J Sport Sci Coach* 2019; 14: 562-568.
11. Soriano, MA, García-Ramos, A, Calderbank, J, Marín, PJ, Sainz de Baranda, P, and Comfort, P. Does sex impact the differences and relationships in the one repetition maximum performance across weightlifting overhead pressing exercises? *J Strength Cond Res* 2020; ahead of print.

12. Soriano, MA, García-Ramos, A, Torres-González, A, Castillo-Palencia, J, Marín, PJ, and Comfort, P. Validity and reliability of a standardized protocol for assessing the one repetition maximum performance during overhead pressing exercises. *J Strength Cond Res* 2020; ahead of print.
13. Haff G. Strength - isometric and dynamic testing. In: Comfort P, Jones PA, J. McMahon J (eds) *Performance assessment in strength and conditioning*. Routledge, 2019.
14. Koo, TK and Li, MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *J Chiropr Med* 2016; 15: 155-163.
15. Baumgartner, TA and Chung, H. Confidence limits for intraclass reliability coefficients. *Meas Phys Educ Exerc Sci* 2001; 5: 179-188.
16. Weir, JP. Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *J Strength Cond Res* 2005; 19: 231-240.
17. Schober, P and Schwarte, LA. Correlation coefficients: appropriate use and interpretation. *Anesth Analg* 2018; 126: 1763-1768.
18. Eid M, Gollwitzer M, Schmitt M. *Statistik und Forschungsmethoden*: Lehrbuch, 2015.
19. Hopkins, WG. Estimating sample size for magnitude-based inferences. *Sportscience* 2017; 21.
20. Weissgerber, TL, Milic, NM, Winham, SJ, and Garovic, VD. Beyond bar and line graphs: time for a new data presentation paradigm. *PLoS Biol* 2015; 13: e1002128.
21. Ho, J, Tumkaya, T, Aryal, S, Choi, H, and Claridge-Chang, A. Moving beyond P values: data analysis with estimation graphics. *Nat Methods* 2019; 16.
22. Contreras, B, Vigotsky, AD, Schoenfeld, BJ, Beardsley, C, McMaster, DT, Reyneke, JHT, et al. Effects of a six-week hip thrust vs. front squat resistance training program on performance in adolescent males: a randomized controlled trial. *J Strength Cond Res* 2017; 31: 999-1008.
23. Laputin, N and Oleshko, V. *Managing the training of weightlifters*. Sportivny, 1986.
24. Roman R. *The training of the weightlifter*. Sportivny,1988.
25. Garhammer, J. A comparison of maximal power outputs between elite male and female weightlifters in competition. *Int J Sport Biomech* 1991; 7: 3–11.
26. Comfort, P and Pearson, SJ. Scaling-which methods best predict performance? *J Strength Cond Res* 28: 1565-1572.
27. Soriano, MA, García-Ramos, A, Torres-González, A, Castillo-Palencia, J, Marín, PJ, Sainz de Baranda, P, et al. Comparison of one repetition maximum performance across three weightlifting overhead pressing exercises and sport groups. I*nt J Sports Physiol Perform* 2019; 15: 862-867.
28. Dorfman, DD. Warren's physical correlate theory: correlation does not imply causation. *Behav Brain Sci* 1981; 4: 192-193.