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Research article

Differences in Mechanical Output between One Repetition Maximum- and Body Mass-Based Load Determination in The Behind-Neck Push Jerk

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Abstract
Body mass (BM) can be used to prescribe loads for some weightlifting derivatives, as an alternative to the one-repetition maximum (1RM). However, the effectiveness of this method has not been investigated in weightlifting overhead pressing derivatives. The primary aim of the study was to investigate the effect of loads determined with percentages of 1RM and BM on kinetic and kinematic characteristics in the behind-neck push jerk (BNPJ). Sixteen recreational male athletes were recruited and performed 3 repetitions of the BNPJ from 40% to 80% of their 1RM and BM, respectively. Two force plates were used to collect kinematic (peak velocity, mean velocity, phase time) and kinetic variables (peak force, mean force, peak power, mean power, and impulse) in the concentric phase. A two-way repeated measures analysis of variance assessed the interaction and the main effect (approaches and intensities) on the dependent variables. The level of significance was set at $p \leq 0.05$. No significant interactions existed between the approaches and intensities in all variables. The main effect approach was not significant in all the kinematic variables, but significant intensity main effects were found. Significant approach and intensity main effects were found in all kinetic variables. All kinetic variables were greater in the 1RM-based approach compared to the BM-based approach. BM can serve as a practical alternative to 1RM for load prescription in the BNPJ when targeting kinematic characteristics. However, 1RM-based loading may be more suitable for maximizing kinetic outputs.

Key words: Weightlifting overhead pressing derivatives; strength and conditioning; overload; power output; biomechanics.

Introduction

Weightlifting exercises (e.g., snatch and clean and jerk) and their derivatives (WLD) include a range of exercises of catching, pulling and overhead pressing (Suchomel et al., 2015b; 2025; Soriano et al., 2019). These exercises are commonly implemented in a wide range of sport populations because of the biomechanical similarities during the lifting movements to generic athletic movements that require rapid triple extension of the hip, knees and ankle joints, while concurrently being able to produce high levels of force and power (Stone et al., 2006). Weightlifting overhead pressing derivatives (WOPD), including variations from the split jerk such as push jerk and push press, share similar movement patterns and lifting strategies involving the dip and thrust phases that mimic the countermovement and propulsion phases of the jump (Lake et al., 2014; Soriano et al., 2021). The ranges of motion in these exercises are similar to many sporting actions and may allow a wide range of athletic populations, that are not weightlifters, to train rapid acceleration of the triple extension movement with moderate to heavy loads (Winter et al., 2016). Therefore, athletes may achieve higher mechanical outputs exceeding those obtained during traditional resistance exercises (Garhammer, 1993; Stone et al., 2006; Kilduff et al., 2007).

The behind-neck push jerk (BNPJ), a variation performed with the barbell positioned on the upper trapezius, has been proposed to increase concentric power output (Flores et al., 2017; Soriano et al., 2019). This is achieved by minimizing horizontal constraints on the upward trajectory of the barbell, thereby facilitating more efficient force application (Flores et al., 2017; Soriano et al., 2019). As training adaptations result from the applied stimulus, investigating the link between external load and mechanical output is critical for informed training prescription (Hori et al., 2005; Cormie et al., 2011a; 2011b). The fact that different loads generate distinct mechanical stimuli underscores the need to understand load-specific characteristics for effective program design (Soriano et al., 2015; 2017; Suchomel et al., 2017; 2018). A recent study investigated the kinetic and kinematic characteristics of the push jerk and its variations, finding higher kinetic and kinematic outputs in heavier loads (Soriano et al., 2024a). Despite this, research examining the impact of varying load prescription methods on BNPJ is lacking.

Traditionally, load prescriptions for WLD have been determined based on a relative percentage of the one-repetition maximum test (1RM) for that exercise (Suchomel et al., 2015a, 2017; Comfort and McMahon, 2015; Comfort et al., 2023). Although effective, employing the 1RM test as an assessment for training prescription may be impractical with novice lifters or large sets of athletes (Loturco et al., 2016). Hence the use of body mass percentage (BM%) to prescribe loads for WLD has been proposed as an alternative method (Lopes dos Santos et al., 2021; Lopes Dos Santos et al., 2022). While this approach is criticized because it fails to account for the individual differences in relative strength and technical skill (Comfort et al., 2023), using the BM% method may be considered practical where 1RM testing is inefficient, such as with novice populations who lack the technical proficiency for frequent testing (Niewiadomski et al., 2008). It has yet to be discussed whether the BM-based approach will lead to different mechanical outputs than the 1RM-based approach in the BNPJ.

Body mass is an important factor in weightlifting as

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it is a sport of weight categories, while research also suggests that BM is positively associated with 1RM in the snatch and clean (Stone et al., 2005; Soriano et al., 2022). However, for novice lifters, this relationship may be affected by their developing technical skill and relative strength. It remains unclear how load prescriptions based on 1RM versus BM may affect BNPJ performance. This study, therefore, aimed to compare system mass kinematics (peak velocity [PV], mean velocity [MV], time and body-mass normalized kinetics (peak force [PF], mean force [MF], peak power [PP], mean power [MP] and impulse) during the BNPJ based on the relative percentage of the participants' 1RM and BM. A secondary aim was to explore the potential influence of BM on 1RM BNPJ in this population with novice experience on this exercise. We hypothesized that kinetic variables would differ significantly between the 1RM- and BM-based loading methods, while kinematic variables would not. Additionally, we hypothesized that BM would be correlated with 1RM in the BNPJ.

Methods

Experimental approach to the problem

A cross-sectional, repeated measures study design was used to compare kinematic and kinetic variables at several intensities based on percentages of 1RM BNPJ and BM. The study involved two experimental sessions with a minimum of 48 hours in between. In the first session, each participant completed an anthropometry measurement and were tested for 1RM BNPJ. In the second session, the participants performed load profiling tests in the BNPJ at relative intensities equivalent of 40%, 50%, 60%, 70%, and 80% of their 1RM BNPJ and BM. In the 1RM-based testing, participants executed the BNPJ at relative intensities based on the pre-determined 1RM test, while in the BM-based testing, relative percentages were determined by the BM of the day as load reference.

Participants

An a-priori power analysis, conducted using G*Power with an alpha of 0.05 and desired power of 0.80 for a repeated-measures ANOVA, indicated that a sample size exceeding 10 would be sufficient to detect a medium effect (f = 0.5). (Kang, 2021). Sixteen recreational male athletes (Age: 28.9 ± 4.3 years; height: 173 ± 6.0 cm; body mass: 80.7 ± 12.8 kg; relative 1RM BNPJ: 1.2 ± 0.2 kg/kg), including amateur team sport athletes and weightlifters, were recruited for this study. Participants had over 2 years of resistance training experience but were novices in the BNPJ exercise. Participants who had experienced musculoskeletal injuries or disorders in the previous 6 months were excluded from the study. All participants were instructed to avoid any strenuous physical activity in the 48-hour leading into each experimental testing. Participants used their preferred weightlifting accessories (e.g., shoes, belts, sleeves) consistently throughout all testing sessions. Written informed consent was obtained from each of the participants before study participation. This study was approved by the Institutional Review Board (IRB) of Fu Jen Catholic University (approval code: C110125).

Procedures

One-Repetition Maximum Test. Participants performed the 1RM test for BNPJ following the protocol defined and modified by Soriano et al. (2021). Technical aspects required to assess the BNPJ during the 1RM and load profiling tests are defined as follows: The participants started with the barbell resting on the upper trapezius and held the barbell with a self-selected grip (Waller et al., 2009). The participants then performed the dip phase of the exercise by performing a countermovement to a self-selected depth. Upon reaching the bottom of the countermovement, the participants performed the thrust phase of the exercise by rapidly extending their lower extremities and projecting the barbell overhead. After extending their lower extremities, the participants bent their knees to drop under the barbell and to catch it overhead. In the catch position, the shoulders remained fully flexed and elbows were at full extension, with knees flexed in a quarter-squat position. The participants were required to demonstrate approximately 1 second of control with the barbell in the catching position and stand up with knees extended to complete the lift whilst maintaining the barbell overhead (Waller et al., 2009; Soriano et al., 2021). Unacceptable lifts included: Projecting the barbell upward through the propulsion phase without bending knees to catch the barbell overhead, dropping under the barbell without locked elbows, or the inability to maintain the catching position over 1 second in the descent phase.

Participants first completed a standardized warm-up which consisted of upper-and lower-body dynamic stretching and continued with the exercise-specific warm-up after a 5-minute rest. The exercise-specific warm up included performing 1 set of 5 repetitions of a 1/4 squat, 1/2 squat, and BNPJ with an Olympic free weight barbell (Ohio Power Bar, Rogue Fitness, USA). Subsequently, participants performed two warm-up sets of loaded BNPJ before the official 1RM test. They first performed the BNPJ for 1 set of 5 repetitions between 50-60% of the maximal perceived effort which was followed by 1 set of 3 repetitions between 70-85% perceived effort with a 5-minute rest in between. Another 5-minute rest was given before the test commenced. In the 1RM testing, participants started from a near-maximal load of 95% of the maximal perceived effort. Each successful attempt was followed by a 2.5–5% increment of the load with a 5-minute rest in between, until the 1RM was reached (Soriano et al., 2021). Participants were instructed to reach their maximal weight within 5 trials. All trials were visually monitored by certified strength and conditioning personnel and video-recorded at the same time to identify mistrials.

Load Profiling Test. This session was separated from the 1RM testing by at least 48 hours. Prior to testing, each participant had their BM recorded, then completed the same standardized warm-up as in the previous session. The load profiling test of 2 different approaches utilized a repeated measures design. To minimize fatigue, the approach with the heavier absolute load was performed first. If the calculated load for the 1RM-based approach was greater than the BM-based approach, participants completed the 1RM-based approach first, progressing from 40%, 50%, 60%, 70%, to 80% of 1RM BNPJ. Conversely, if the load in the BM-based approach was greater, participants began with the BM-based approach, progressing from the equivalent relative loads in percentage of BM. A 15-minute rest period separated the two approaches. After the warm-up, participants completed 1 set of 3 consecutive repetitions of the BNPJ at each of the relative load including 40%, 50%, 60%, 70% and 80% of 1RM BNPJ, with a 5-minute rest provided between each intensity. After 15 minutes, the same order of testing and the same resting time were repeated for the BM-based approach. The selected load range of 40-80% 1RM was chosen to assess mechanical output across a range of loads typically prescribed to develop both the force and velocity components of the force-velocity curve (Comfort et al., 2023). As recommended by Suchomel et al. (2015a), the loads in both load profile testing sessions were performed in a progressive order to replicate a typical resistance training session. All trials were visually monitored by certified strength and conditioning personnel and video-recorded at the same time to identify mistrials.

Data collection and processing. Two force plates (9260AA, Kistler., Winterthur, Switzerland) were used to collect kinetic data in the load profile testing (Soriano et al., 2024b). The participants performed the lifts while keeping both feet standing on forces plate of the corresponding side. The force plates were interfaced to an analog-to-digital converter (5695B, Kistler., Winterthur, Switzerland) to transmit data. Vertical ground reaction force (VGRF) was collected at 1,000 Hz. Subsequent analysis of the VGRF data was done using a custom-designed Microsoft Excel spreadsheet (version 2016, Microsoft Inc., Redmond, WA, USA). The acceleration of the system center of mass (COM) was obtained by subtracting the system weight (barbell plus body weight averaged over a one-second period of weighting phase) from VGRF and then dividing this by system mass on a sample-by-sample basis. This acceleration data was then integrated using the trapezoidal rule to calculate the velocity-time and displacement-time data. Power was calculated by displacing system mass resulting as the product of the force and velocity of the COM derived from the force plates as recommended in the literature (Soriano et al., 2019, 2023; Suchomel et al., 2025). All force-time variables were analyzed in propulsive phases (Soriano et al., 2024b), which was deemed to have started when velocity transitioned from negative to positive and finished at the instance of propulsion peak velocity (Figure 1). The threshold for the onset of movement was defined as the point at which the VGRF was reduced by a threshold equal to 5 times the standard deviations of the system weight during the period of quiet standing (Soriano et al., 2024b). Peak force (PF) refers to the maximum vertical ground reaction force (VGRF) recorded during the propulsive phase. Mean force (MF) indicates the average VGRF observed during the propulsive phase. Peak velocity (PV) represents the maximum COM velocity achieved during the propulsive phase. Mean velocity (MV) is calculated by dividing the sum of COM-displacement in the propulsive phase. Peak power (PP) signifies the maximum power output attained during the propulsive phase. Mean power (MP) represents the average power output during the propulsive phase. Impulse (IMP) is defined as the force exerted multiplied by the time taken to produce it during the propulsive phase. Time is the duration of the propulsive phase, which is the time interval between zero velocity and concentric peak velocity.

Statistical analysis

All data are reported as the mean ± SD. For each variable, the mean output of the three trials was taken forward for statistical analysis. A two-way mixed effect model intraclass correlation coefficients (ICCs) and coefficients of variation (CV) were used to determine the reliability of the dependent variables. Minimal acceptable reliability and variability were determined with an ICC ≥ 0.70 and a CV of ≤ 10% (Turner et al., 2015). A series of 2 (approach) × 5 (intensity) two-way repeated measures analysis of variance (ANOVA) was used to compare interaction and the main effect differences of the selected variables at the various intensities (40%, 50%, 60%, 70% and 80%) based on 1RM and BM. Post hoc analyses were performed using Bonferroni correction.

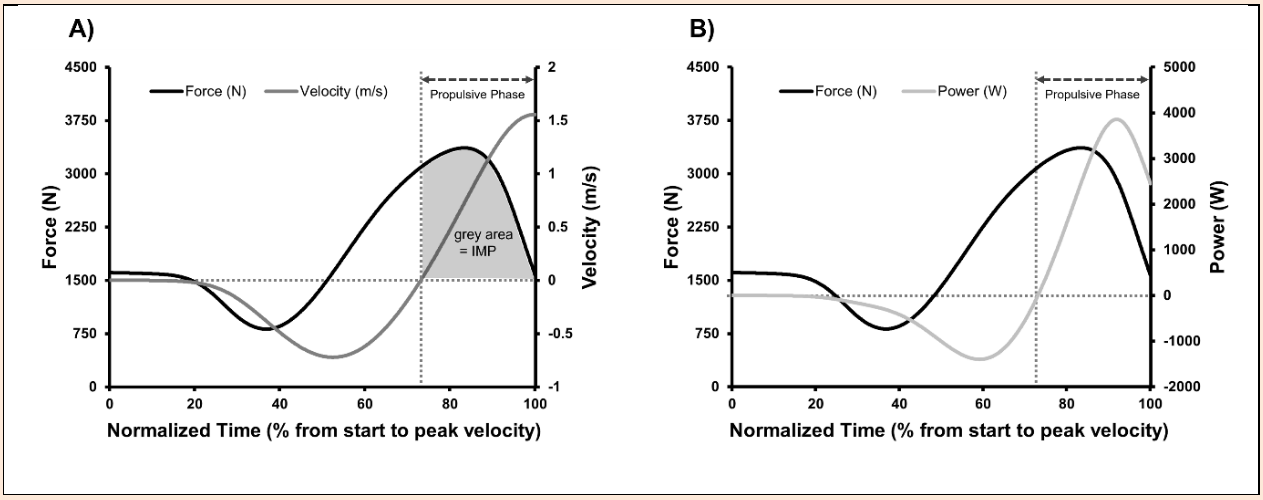

Figure 1. Representative (A) force- and velocity-time curves, and (B) force- and power-time curves for the behind-the-neck push jerk performed at 80% of 1RM. The figure illustrates the propulsive phase, the period from zero velocity to peak velocity, where all kinetic and kinematic variables were calculated. Impulse (IMP), shown as the shaded area, is the integral of the force-time curve during this phase.

Table 1. **Post-Hoc comparisons of approaches within each percentage intensity. Main effect and interaction of 2 approaches x 5 intensities on kinetic and kinematic variables.**

Variable	40%			50%			60%			70%			80%		
	1RM	BM	g	1RM	BM	g	1RM	BM	g	1RM	BM	g	1RM	BM	g
PF (N/kg)	31.13±3.83	29.80±4.00	*0.55 [0.03,1.07]	33.49±4.20	31.68±4.12	*0.93 [0.39,1.47]	35.46±4.67	33.39±3.95	*1.14 [0.59,1.69]	36.79±4.68	34.73±3.95	*0.86 [0.33,1.39]	38.07±4.70	36.07±3.93	*0.76 [0.24,1.28]
MF (N/kg)	26.66±2.60	25.22±2.54	*0.86 [0.33,1.39]	28.78±2.89	26.99±2.61	*1.11 [0.56,1.66]	30.67±3.32	28.72±2.48	*1.24 [0.68,1.80]	32.21±3.47	30.09±2.67	*0.99 [0.45,1.53]	33.64±3.66	31.47±2.70	*0.92 [0.38,1.46]
PV (m/s)	1.46±0.22	1.40±0.23	0.38 [-0.13,0.89]	1.49±0.19	1.45±0.21	0.38 [-0.13,0.89]	1.53±0.17	1.51±0.17	0.28 [-0.23,0.79]	1.56±0.16	1.53±0.18	0.35 [-0.16,0.86]	1.58±0.14	1.57±0.16	0.22 [-0.29,0.73]
MV (m/s)	0.86±0.14	0.83±0.14	0.4 [-0.11,0.91]	0.87±0.12	0.85±0.13	0.27 [-0.24,0.78]	0.88±0.11	0.87±0.10	0.3 [-0.21,0.81]	0.88±0.10	0.88±0.12	0.19 [-0.32,0.70]	0.89±0.09	0.89±0.10	0.07 [-0.44,0.58]
PP (W/kg)	32.69±6.52	29.26±5.86	*0.88 [0.35,1.41]	35.63±6.46	32.56±6.55	*0.7 [0.18,1.22]	39.42±6.48	36.29±5.23	*0.85 [0.32,1.38]	42.46±6.20	39.07±5.80	*0.86 [0.33,1.39]	45.40±6.06	42.06±5.40	*0.87 [0.34,1.40]
MP (W/kg)	21.74±4.61	19.56±3.93	*0.98 [0.44,1.52]	23.38±4.47	21.57±4.47	*0.69 [0.17,1.21]	25.58±4.68	23.65±3.78	*1.03 [0.49,1.57]	27.11±4.56	25.13±4.45	*0.83 [0.30,1.36]	28.72±4.52	26.73±4.27	*0.8 [0.28,1.32]
Imp (N·s/kg)	2.12±0.31	1.91±0.30	*0.89 [0.36,1.42]	2.32±0.31	2.12±0.33	*0.76 [0.24,1.28]	2.57±0.31	2.37±0.26	*0.79 [0.27,1.31]	2.81±0.30	2.57±0.29	*0.88 [0.35,1.41]	3.05±0.30	2.78±0.26	*0.94 [0.40,1.48]
Time (s)	0.17±0.03	0.16±0.04	0.24 [-0.27,0.75]	0.18±0.03	0.17±0.03	0.36 [-0.15,0.87]	0.19±0.03	0.18±0.04	0.18 [-0.33,0.69]	0.20±0.04	0.19±0.04	0.39 [-0.12,0.90]	0.21±0.04	0.20±0.04	0.43 [-0.08,0.94]

1RM = 1 repetition maximum; BM = body mass; g = Hedge's g; PF = relative concentric peak force; MF = relative concentric mean force; PP = relative concentric peak power; MP = relative concentric mean power; PV = concentric peak velocity; MV = concentric mean velocity; Imp = relative concentric impulse; Time = propulsive phase time. * Significant difference between approaches ($p < 0.05$).

The criterion level for significance was defined by $p \leq 0.05$. Effect sizes for post-hoc comparisons were calculated using Hedge's g to adjust for the small sample size. The magnitude of difference was interpreted as follows: 0.2 represented a small effect, 0.5 a medium effect, and 0.8 a large effect. Pearson product-moment correlation coefficient (R) and coefficient of determination (R2) were calculated to identify the relationship between the participants' 1RM and BM. The strength of the correlation was interpreted with absolute values of R from 0.00–0.10 considered negligible; 0.10–0.39, weak; 0.40–0.69, moderate; 0.70–0.89, strong; and 0.90–1.00, very strong (Schober et al., 2018). All statistical analyses were conducted with SPSS 20.0 (IBM, New York, NY, USA).

Results

All 1RM- and BM-based variables demonstrated acceptable absolute and relative reliability values, with all confidence intervals (CIs) reported at the 95% level. For 1RM, ICCs ranged from 0.757 (0.539-0.895) to 0.978 (0.950-0.991), and CVs ranged from 1.47% (1.09–2.27%) to 7.04% (5.20–10.89%). For BM, ICCs ranged from 0.849 (0.706-0.922) to 0.968 (0.934-0.987), and CVs ranged from 1.39% (1.03–2.15%) to 6.31% (4.66–9.76%). The average 1RM was 96.8 ± 16.5 kg, with a relative 1RM of 1.2 ± 0.2 kg/kg of bodyweight.

No significant interactions existed between the approaches and intensities for all the selected variables. There were no significant approach main effects for PV ($p = 0.96$), MV ($p = 0.11$) or Time ($p = 0.12$). Significant approach main effects were found for PF, MF, PP, MP and IMP (all $p < 0.001$). Significant intensity main effects were found for PF, MF, PV, MV, PP, MP, IMP and Time (all $p < 0.001$).

Post-hoc comparisons, as detailed in Table 1 and Figure 2, revealed that the 1RM approach resulted in significantly higher values across all intensities for PF, MF, PP, MP, and IMP compared to the BM approach. Moderate to large effects were observed for PF (g = 0.55 to 1.14), MF (g = 0.86 to 1.24), PP (g = 0.85 to 1.03), MP (g = 0.69 to 1.03), and IMP (g = 0.79 to 0.94). Trivial to small effect sizes were observed for PV, MV and Time (g = 0.07 to 0.43).

A moderate correlation was observed between BNPJ 1RM and participants' BM (R2 = 0.29 [0.01-0.66], R = 0.54 [0.05-0.81], $p = 0.032$) (Figure 3).

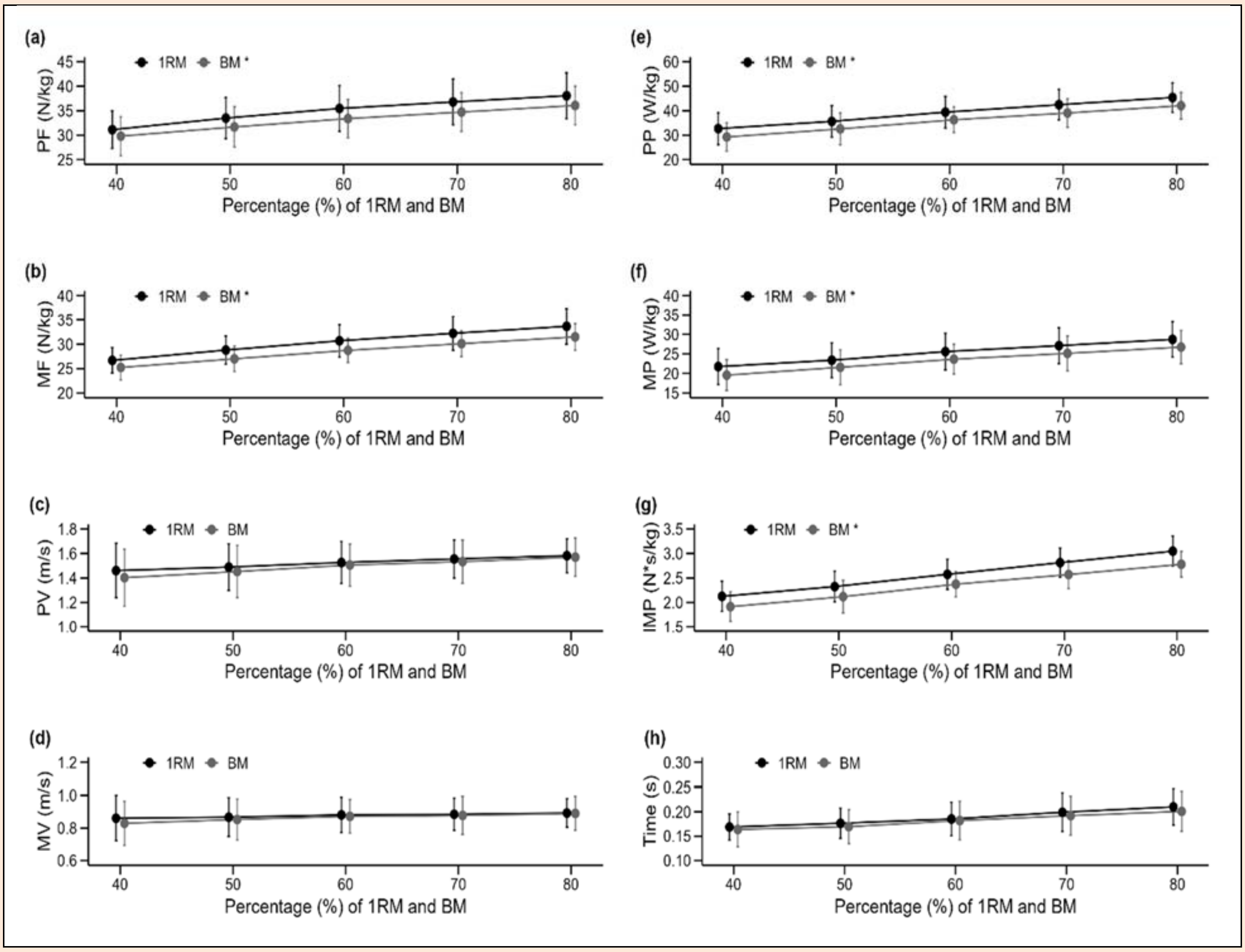

Figure 2. Effects of approach and intensity on kinetics and kinematics. Data are presented as mean ± SD. Compared to the BM approach, the 1RM approach resulted in significantly higher PF, MF, PP, MP, and IMP ($p < 0.05$, presented with * in the figure).

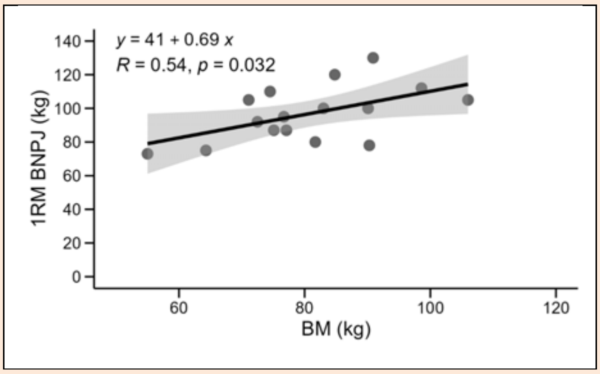

Figure 3. Correlation between the participants' 1RM BNPJ and BM. 1RM = 1 repetition maximum; BNPJ = behind-neck push jerk; BM = body mass; * Moderate correlation was observed.

Discussion

This study aimed to compare the effects of two load determination methods, the traditional 1RM approach and the novel BM approach, on the kinematics and kinetics of the BNPJ. Our hypothesis was supported by the findings that kinetic variables (PF, MF, PP, MP, and IMP) differ significantly between 1RM-based approach and the BM-based approach. On the other hand, kinematic variables (PV, MV, and Time) did not differ significantly between the two loading approaches. While both methods may yield similar kinematic profiles, the 1RM-based approach results in greater force, power, and impulse output during the BNPJ. Additionally, a moderate correlation was observed between 1RM and BM. Therefore, 1RM-based prescriptions are recommended to maximize force and power output in the BNPJ. While the BM-based approach offers a convenient alternative, practitioners must consider its production of suboptimal kinetic outputs and that individual differences in relative strength will significantly impact the training outcomes.

This study provides novel insights into the effects of different load determination methods on BNPJ performance. Our results demonstrated significantly greater PF, MF, PP, MP, and impulse values with the 1RM-based approach compared to the BM-based approach. This aligns with previous findings of higher kinetic outputs in higher loads in WOPDs (Lake et al., 2014; Flores et al., 2017; Soriano et al., 2024a). The greater external loads used in the 1RM-based method, where the average 1RM was 1.2 ± 0.2 times body mass in our participants, likely contributed to this finding. Furthermore, heavier loads in the BNPJ tend to be associated with distinct movement strategies, such as increased dip depth and longer contraction times, which may contribute to higher kinetic values. The efficacy of the BM-based approach is likely dependent on the lifter's training status. In skilled lifters, high relative strength makes body mass a poor predictor of performance. In contrast, this factor is less developed in novice athletes, which may explain the moderate correlation found in our sample. This suggests the BM method can be a practical, though suboptimal, tool for prescribing loads for this novice population. For athletes seeking to optimize strength and power gains, the 1RM-based approach may be more advantageous (Kawamori and Haff, 2004).

Although previous studies have investigated BM-based load that maximizes kinetic and kinematic variables in other WLDs, including pulling and catching derivatives (Soriano et al., 2019; Lopes dos Santos et al., 2021; Lopes Dos Santos et al., 2022), these studies did not directly compare BM- and 1RM-based approaches. This study is the first to investigate the differences of mechanical output between the two approaches. Our findings suggest that the BM-based method may prescribe lighter loads, therefore not a complete substitute for 1RM when training for maximal force and power output in the BNPJ. Future research should investigate whether these two prescription approaches produce different mechanical outputs as well in various other WLDs. Additionally, as this study only investigates acute outputs, future investigations should explore the long-term effects of both approaches on various training adaptations, such as strength, hypertrophy or power. Finally, as the current findings are specific to a population with novice weightlifting experience, future research should compare these prescription methods in athletes with higher relative strength, where the relationship between BM and 1RM may differ.

The 1RM- and BM-based load setting approaches resulted in no significant differences in kinematic variables (PV, MV and Time; $p > .05$). This result is consistent with recent investigations into WLDs like the push jerk, push press, and split jerk, finding COM velocity to maintain relative stable across loads (Soriano et al., 2024a; Suchomel et al., 2025). This may contrast with the typical load-velocity relationship observed in traditional resistance training exercises, where velocity tends to decrease as load increases (Banyard et al., 2018). Notably, our kinematic analyses focused on COM velocity, which in WLD may not follow the typical load-velocity relationship (Suchomel et al., 2025). Although 1RM- and BM-based load setting approaches produced comparable COM velocities, the 1RM-based approach produced higher kinetic outputs at the same time. Consequently, while the BM-based method can serve as an alternative prescription method, it may be suboptimal for developing qualities such as force or power.

The use of an individual's BM as an alternative to the 1RM test for load determination in WLDs arose from a practical need to simplify the prescription process especially in untrained or novel lifters (Lopes dos Santos et al., 2021). However, the relationship between the participant's 1RM BNPJ and their BM was not identified in previous studies (Soriano et al., 2019; Lopes dos Santos et al., 2021). A moderate correlation was observed, indicating a potential association between BM and maximum BNPJ performance in this population. This is in agreement with previous studies, supporting that BM is a contributing factor in weightlifting performance (Stone et al., 2005; Soriano et al., 2022). However, our data also showed that BM can only explain approximately 29% of the variance in 1RM BNPJ performance. It is crucial to recognize that lifting performance for BNPJ, and most WLDs in general, is largely affected by technical skill, coordination, and relative strength as well (Suchomel et al., 2017; Soriano et al., 2019). Therefore, these factors ought to be taken into consideration when prescribing loads using an individual's BM as reference.

The findings of this study should be considered alongside a few limitations. First, although BM% prescriptions are sensitive to daily body mass fluctuations, any practical change in barbell load is limited by the minimum available loading increment (e.g., 1 kg). Long-term monitoring of BM is therefore recommended for precise prescription (Vargas et al., 2019). Furthermore, our participant sample comprised recreational athletes with novice experience in the BNPJ. The present results may not be directly applicable to other populations, such as skilled weightlifters with high relative strength. Relative strength can have a significant impact on the effectiveness of the BM approach. This factor, which varies considerably between individuals, should be considered when using BM percentages to determine loads. Greater relative strength may allow an individual to perform WOPD exercises with higher loads using 1RM percentages rather than BM percentages, while someone with lower relative strength may not. It is recommended that future research could investigate whether BM could be used to prescribe intensity for populations with different relative strengths. Additionally, direct comparisons between the current study's findings and previous research may be limited. This is primarily attributed to methodological discrepancies, particularly in data normalization. While this study normalized kinetic variables to the participants' body mass to minimize intersample variability, some weightlifting studies did not employ this approach (Flores et al., 2017).

Conclusion

In populations with novice BNPJ experience, the 1RM and BM-based load determination approaches should not be used interchangeably as we found the 1RM-based approach may produce higher kinetic outputs than the BM-based approach. On the other hand, the two approaches may produce similar kinematic characteristics. Coaches and athletes can use these findings to inform them of their training strategies. When incorporating the BNPJ into strength and conditioning programs, the choice between 1RM- and BM-based loading should be guided by the desired training adaptation. For maximizing force and power output, 1RM-based loading is recommended. BM-based approach may offer a more convenient alternative; however, practitioners should be aware of the limitations of using BM as a load prescription method as differences in relative strength may significantly impact how individuals respond to specific training loads.

Acknowledgements

The experiments comply with the current laws of the country in which they were performed. The authors have no conflict of interest to declare. The datasets generated during and/or analyzed during the current study are not publicly available but are available from the corresponding author who was an organizer of the study.

References

Banyard, H.G., Nosaka, K., Vernon, A.D. and Haff, G.G. (2018) The reliability of individualized load-velocity profiles. *International Journal of Sports Physiology and Performance* **13**, 763-769. https://doi.org/10.1123/ijspp.2017-0610

Comfort, P., Haff, G.G., Suchomel, T.J., Soriano, M.A., Pierce, K.C., Hornsby, W.G., Haff, E.E., Sommerfield, L.M., Chavda, S., Morris, S.J., Fry, A.C., and Stone, M.H. (2023) National strength and conditioning association position statement on weightlifting for sports performance. *Journal of Strength & Conditioning Research* **37**, 1163. https://doi.org/10.1519/JSC.0000000000004476

Comfort, P. and McMahon, J.J. (2015) Reliability of maximal back squat and power clean performances in inexperienced athletes. *Journal of Strength and Conditioning Research* **29**, 3089-3096. https://doi.org/10.1519/JSC.0000000000000815

Cormie, P., McGuigan, M.R. and Newton, R.U. (2011a) Developing maximal neuromuscular power: part 1--biological basis of maximal power production. *Sports Medicine* **41**, 17-38. https://doi.org/10.2165/11537690-000000000-00000

Cormie, P., McGuigan, M.R. and Newton, R.U. (2011b) Developing maximal neuromuscular power: part 2 - training considerations for improving maximal power production. *Sports Medicine* **41**, 125-146. https://doi.org/10.2165/11538500-000000000-00000

Flores, F.J., Sedano, S. and Redondo, J.C. (2017) Optimal load and power spectrum during jerk and back jerk in competitive weightlifters. *Journal of Strength and Conditioning Research* **31**, 809-816. https://doi.org/10.1519/JSC.0000000000001544

Garhammer, J. (1993) A review of power output studies of olympic and powerlifting: methodology, performance prediction, and evaluation tests. *Journal of Strength and Conditioning Research* **7**, 76. https://doi.org/10.1519/00124278-199305000-00002

Hori, N., Newton, R.U., Nosaka, K. and Stone, M.H. (2005) Weightlifting exercises enhance athletic performance that requires high-load speed strength. *Strength & Conditioning Journal* **27**, 50. https://doi.org/10.1519/00126548-200508000-00008

Kang, H. (2021) Sample size determination and power analysis using the G*Power software. *Journal of Educational Evaluation for Health Professions* **18**, 17. https://doi.org/10.3352/jeehp.2021.18.17

Kawamori, N. and Haff, G.G. (2004) The optimal training load for the development of muscular power. *Journal of Strength and Conditioning Research* **18**, 675-684. https://doi.org/10.1519/00124278-200408000-00051

Kilduff, L.P., Bevan, H., Owen, N., Kingsley, M.I.C., Bunce, P., Bennett, M., and Cunningham, D. (2007) Optimal loading for peak power output during the hang power clean in professional rugby players. *International Journal of Sports Physiology and Performance* **2**, 260-269. https://doi.org/10.1123/ijspp.2.3.260

Lake, J.P., Mundy, P.D. and Comfort, P. (2014) Power and impulse applied during push press exercise. *Journal of Strength and Conditioning Research* **28**, 2552-2559. https://doi.org/10.1519/JSC.0000000000000438

Lopes Dos Santos, M., Berton, R., Jagodinsky, A.E., Torry, M.R. and Lagally, K.M. (2022) The effect of load based on body mass percentage on peak power output in the hang power clean, hang high pull, and mid-thigh clean pull. *Journal of Sports Medicine and Physical Fitness* **62**, 457-466. https://doi.org/10.23736/S0022-4707.21.12243-1

Lopes dos Santos, M., Jagodinsky, A., Lagally, K.M., Tricoli, V. and Berton, R. (2021) Determining the peak power output for weightlifting derivatives using body mass percentage: a practical approach. *Frontiers in Sports and Active Living* **3**. https://doi.org/10.3389/fspor.2021.628068

Loturco, I., Pereira, L.A., Cal Abad, C.C., Gil, S., Kitamura, K., Kobal, R., and Nakamura, F.Y. (2016) Using bar velocity to predict the maximum dynamic strength in the half-squat exercise. *International Journal of Sports Physiology and Performance* **11**, 697-700. https://doi.org/10.1123/ijspp.2015-0316

Niewiadomski, W., Laskowska, D., Gąsiorowska, A., Cybulski, G., Strasz, A. and Langfort, J. (2008) Determination and prediction of one repetition maximum (1RM): safety considerations. *Journal of Human Kinetics* **19**, 109-120. https://doi.org/10.2478/v10078-008-0008-8

Schober, P., Boer, C. and Schwarte, L.A. (2018) Correlation coefficients: appropriate use and interpretation. *Anesthesia and Analgesia* **126**, 1763. https://doi.org/10.1213/ANE.0000000000002864

Soriano, M.A., García-Ramos, A., Torres-González, A., Castillo-Palencia, J., Ayuso, V., Marín, P. J., and Comfort, P. (2021) Validity and reliability of a standardized protocol for assessing the one repetition maximum performance during overhead pressing exercises. *Journal of Strength and Conditioning Research* **35**, 2988-2992. https://doi.org/10.1519/JSC.0000000000003284

Soriano, M.A., Jiménez-Ormeño, E., Amaro-Gahete, F.J., Haff, G.G. and Comfort, P. (2022) How does lower-body and upper-body strength relate to maximum split jerk performance? *Journal of Strength & Conditioning Research* **36**, 2102. https://doi.org/10.1519/JSC.0000000000004289

Soriano, M.A., Jiménez-Ormeño, E., Lake, J.P., McMahon, J.J., Gallo-Salazar, C., Mundy, P., and Comfort, P. (2024a) Kinetics and kinematics of the push press, push jerk, and split jerk. *Journal of Strength & Conditioning Research* **38**, 1359. https://doi.org/10.1519/JSC.0000000000004810

Soriano, M.A., Jiménez-Reyes, P., Rhea, M.R. and Marín, P.J. (2015) The optimal load for maximal power production during lower-body resistance exercises: a meta-analysis. *Sports Medicine* **45**, 1191-1205. https://doi.org/10.1007/s40279-015-0341-8

Soriano, M.A., Kipp, K., Lake, J.P., Suchomel, T.J., Marín, P.J., Sainz De Baranda, M.P., and Comfort, P. (2023) Mechanical power production assessment during weightlifting exercises. a systematic review. *Sports Biomechanics* **22**, 633-659. https://doi.org/10.1080/14763141.2020.1747529

Soriano, M.A., Lake, J., Comfort, P., Suchomel, T.J., McMahon, J.J., Jiménez-Ormeño, E., and Sainz de Baranda, P. (2024b) No differences in weightlifting overhead pressing exercises kinetics. *Sports Biomechanics*, 1-13. https://doi.org/10.1080/14763141.2021.1993983

Soriano, M.A., Suchomel, T.J. and Comfort, P. (2019) Weightlifting overhead pressing derivatives: a review of the literature. *Sports Medicine* **49**, 867-885. https://doi.org/10.1007/s40279-019-01096-8

Soriano, M.A., Suchomel, T.J. and Marín, P.J. (2017) The optimal load for maximal power production during upper-body resistance exercises: a meta-analysis. *Sports Medicine* **47**, 757-768. https://doi.org/10.1007/s40279-016-0626-6

Stone, M.H., Pierce, K.C., Sands, W.A. and Stone, M.E. (2006) Weightlifting: a brief overview. *Strength and Conditioning Journal* **28**, 50. https://doi.org/10.1519/00126548-200604000-00001

Stone, M.H., Sands, W.A., Pierce, K.C., Carlock, J., Cardinale, M. and Newton, R.U. (2005) Relationship of maximum strength to weightlifting performance. *Medicine and Science in Sports and Exercise* **37**, 1037.

Suchomel, T.J., Beckham, G.K. and Wright, G.A. (2015a) Effect of various loads on the force-time characteristics of the hang high pull. *Journal of Strength and Conditioning Research* **29**, 1295-1301. https://doi.org/10.1519/JSC.0000000000000748

Suchomel, T.J., Comfort, P. and Lake, J.P. (2017) Enhancing the force-velocity profile of athletes using weightlifting derivatives. *Strength and Conditioning Journal* **39**, 10. https://doi.org/10.1519/SSC.0000000000000275

Suchomel, T.J., Comfort, P. and Stone, M.H. (2015b) Weightlifting pulling derivatives: rationale for implementation and application. *Sports Medicine* **45**, 823-839. https://doi.org/10.1007/s40279-015-0314-y

Suchomel, T.J., Kissick, C.R., Techmanski, B.S., Mann, J.B. and Comfort, P. (2025) Velocity-based training with weightlifting derivatives: barbell and system velocity comparisons. *Journal of Strength and Conditioning Research* **39**, 135-146.

Suchomel, T.J., Nimphius, S., Bellon, C.R. and Stone, M.H. (2018) The importance of muscular strength: training considerations. *Sports Medicine* **48**, 765-785. https://doi.org/10.1007/s40279-018-0862-z

Turner, A., Brazier, J., Bishop, C., Chavda, S., Cree, J. and Read, P. (2015) Data analysis for strength and conditioning coaches: using excel to analyze reliability, differences, and relationships. *Strength and Conditioning Journal* **37**, 76. https://doi.org/10.1519/SSC.0000000000000113

Vargas, S., Petro, J.L., Romance, R., Bonilla, D.A., Florido, M.Á., Kreider, R.B., Schoenfeld, B.J., and Benítez-Porres, J. (2019) Comparison of changes in lean body mass with a strength- versus muscle endurance-based resistance training program. *European Journal of Applied Physiology* **119**, 933-940. https://doi.org/10.1007/s00421-019-04082-0

Waller, M., Piper, T. and Miller, J. (2009) Overhead pressing power/strength movements. *Strength and Conditioning Journal* **31**, 39-49. https://doi.org/10.1519/SSC.0b013e3181b95a49

Winter, E.M., Abt, G., Brookes, F.B.C., Challis, J.H., Fowler, N.E., Knudson, D.V., Knuttgen, H.G., Kraemer, W.J., Lane, A.M., van Mechelen, W., Morton, R.H., Newton, R.U., Williams, C., and Yeadon, M.R. (2016) Misuse of "power" and other mechanical terms in sport and exercise science research. *Journal of Strength and Conditioning Research* **30**, 292-300. https://doi.org/10.1519/JSC.0000000000001101

Key points

- Kinematic outputs are similar whether using 1RM or BM percentages for loads from 40% to 80% in the BNPJ.
- 1RM-based loading generates greater kinetic outputs in the BNPJ compared to BM-based loading.
- Prioritize 1RM-based loading for maximizing force and power; BM-based loading is an alternative for achieving similar kinematic (e.g. velocity) outputs.

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