No Differences in Weightlifting Overhead Pressing Exercises Kinetics

Kinetics of the PP, PJ and SJ

Soriano, M.A. Lake, J. Comfort, P. Suchomel, T.J. McMahon, J.J. Jiménez-Ormeño, E. & Sainz de Baranda, P

Abstract

This study aimed to compare the kinetics between the push press (PP), push jerk (PJ), and split jerk (SJ). Sixteen resistance-trained participants (12 men and 4 women; age: 23.8 ± 4.4 years; height: 1.7 ± 0.1 m; body mass: 75.7 ± 13.0 kg; weightlifting experience: 2.2 ± 1.3 years; one repetition maximum [1RM] PP: 76.5 ± 19.5 kg) performed 3 repetitions each of the PP, PJ and SJ at a relative load of 80% 1RM PP on a force platform. The kinetics (peak and mean force, peak and mean power, and impulse) of the PP, PJ and SJ were determined during the dip and thrust phases. Dip and thrust displacement and duration were also calculated for the three lifts. In addition, the inter-repetition reliability of each variable across the three exercises was analyzed. Moderate to excellent reliability was evident for the PP (Intraclass correlation coefficient [ICC] = 0.91 – 1.00), PJ (ICC = 0.86 – 1.00) and SJ (ICC = 0.55 – 0.99) kinetics. One-way analysis of variance revealed no significant or meaningful differences ($p > 0.05$, $\eta^2 \leq 0.010$) for any kinetic measure between the PP, PJ, and SJ. In conclusion, there were no differences in kinetics between the PP, PJ, and SJ when performed at the same standardized load of 80% 1RM PP.

Key words: push press, push jerk, split jerk, power output, biomechanics, force platform.

Introduction

Weightlifting exercises and their derivatives have been suggested to be effective training tools to improve sports performance (Chiu & Schilling, 2005; Hori, Newton, Nosaka, & Stone, 2005; Suchomel, Comfort, & Lake, 2017; Suchomel, Comfort, & Stone, 2015). Researchers have highlighted that these exercises imitate sport-specific movements by means of performing a forceful triple extension pattern of the hips, knees and ankles (plantar flexion), while concurrently producing high rates of force development and power (Comfort, Allen, & Graham-Smith, 2011a; Suchomel et al., 2015). Moreover, researchers have shown that performance in weightlifting variations such has the hang power clean is correlated with sprinting ($r = -0.58$, $p < 0.01$), jumping ($r = 0.41$, $p < 0.05$) and change of direction performance ($r = -0.41$, $p < 0.05$) (Hori et al., 2008). In addition, results of a recent meta-analysis revealed that training with weightlifting exercises and their derivatives is more effective for increasing jumping performance than employing traditional resistance training in resistance-trained participants (~5% difference; effect size [ES] = 0.64, $p < 0.001$) (Hackett, Davies, Soomro, & Halaki, 2016).

Researchers have demonstrated that exercise variation impacts one repetition maximum (1RM) performance between weightlifting power clean and overhead pressing exercises (Kelly, McMahon, & Comfort, 2015; Soriano et al., 2019). Similarly, the kinetics can also be affected by weightlifting variations, with the majority of research in this area focused on weightlifting pulling and catching derivatives (Comfort, Allen, & Graham-Smith, 2011b; Suchomel et al., 2015; Suchomel, Wright, Kernozek, & Kline, 2014). For example, Comfort et al. (2011b) determined that peak force and power during the mid-thigh power clean and mid-thigh clean pull were significantly greater ($p < 0.001$) than equivalent data from the hang power clean (~19%, ~28%, respectively) and power clean (~14%, ~12% difference, respectively). However, there were no significant differences in the peak force, rate of force development and power between the mid-thigh power clean and mid-thigh clean pull. Authors attributed these similarities in kinetics to similar kinematics of the propulsion phase between lifts. Similarly, Suchomel et al. (2014) found a significantly higher peak power output during the jump shrug compared with hang clean (30%, $p < 0.001$) and high pull (19%, $p < 0.001$). Additionally, authors reported significantly higher power outputs in the hang high pull when compared to the hang power clean exercise (13%, $p < 0.001$). Altogether, these findings indicate that exercise selection impacts the kinetics (e.g. force, power) of weightlifting pulling and catching derivatives (Suchomel et al., 2017). However, while the kinetics of the weightlifting pulling and catching derivatives have been studied extensively, little information exists about the weightlifting overhead pressing derivatives.

Weightlifting overhead pressing exercises such as the push press (PP), push jerk (PJ) and split jerk (SJ) are widely used by practitioners to enhance athlete ability to generate high rates of force development and power (Comfort et al., 2016; Lake, Mundy, & Comfort, 2014; Soriano, Suchomel, & Comfort, 2019). The PP, PJ and SJ have similar lower-body movement pattern, which is comparable to a countermovement jump (CMJ) and the propulsion phase of other weightlifting derivatives such as the hang power clean, as previously stablished (Hori et al., 2008; Lake et al., 2014; Soriano et al., 2019). The lifting strategy of the PP, PJ and SJ involve the dip and thrust phases. The dip is the shallow squat which corresponds to the sum of the unweighing and braking phases (similar to the CMJ), whereas the thrust is the rapid propulsion phase via extension of the hips and knees, and plantar flexion of the ankles. It is during the thrust phase where the highest rate of force development, barbell velocity and, consequently, power has been recorded (Lake, Lauder, & Dyson, 2007; Lake et al., 2014). A strictly vertical movement, and optimal duration and displacement during the dip and thrust phases are key aspects of success in the PP, PJ, and SJ (Soriano et al., 2019). However, to the authors knowledge, the differences in power, force or impulse during weightlifting overhead pressing variations (PP, PJ or SJ) are not known and by studying these data we could help practitioners make informed decisions about program design and weightlifting overhead pressing exercises performance.

Therefore, the aim of this study was to compare the kinetics between the PP, PJ and SJ exercises. Briefly, studying peak and mean force enables the coach to identify key elements of the athlete's force generating capacity; power describes the rate at which work is performed (based on the system centre of mass [COM]) (Lake, Lauder, & Smith, 2012; Turner et al., 2020); impulse explains the mean net force (force minus weight) and duration of force application and is directly proportional to the subsequent momentum of the mass of interest. It has been contested that because the impulse-momentum relationship perfectly describes the requirements for "powerful" movements, strength and conditioning coaches should focus on examining the underpinning components of net impulse: net force and time (duration of force application) (Turner et al., 2020), therefore propulsion phase duration will also be investigated. A further aim of this study was to determine the inter-repetition reliability of each variable across the three exercises. Reliability is important to be confident that any changes in performance are due to factors other than errors associated with the test. In this case, determining within-session reliability is important for quantifying the consistency of performance within the test (Comfort, Jones, & McMahon, 2018). It was hypothesized that PP, PJ, and SJ dip and thrust phase kinetics would not be different when performed with a standardized load, because a similar lower-body lifting strategy (kinematics) will be used (Comfort, McMahon, & Fletcher, 2013; Soriano et al., 2019).

Methods

Participants

Sixteen healthy resistance-trained participants, (12 men and 4 women; age: 23.8 ± 4.4 years; height: 1.7 ± 0.1 m; body mass: 75.7 ± 13.0 kg; weightlifting training experience: 2.2 ± 1.3 years; 1RM PP: 76.5 ± 19.5 kg) took part in this study. Participants were competitors in CrossFit®, rugby, volleyball, swimming, track and field, and weightlifting (regional and national championships) and had $\geq$ 6 months of weightlifting experience. The PP, PJ and SJ were regularly performed ($\geq$ 3 x a week) in their respective strength and conditioning training preparation. There were no highly skilled weightlifters in this study, with seven participants competing at regional and national level for at least 1 year. Participants were assessed by a certified strength and conditioning specialist before the testing session to ensure that the exercises (PP, PJ and SJ) were performed adequately. Participants were asked to replicate their fluid and food intake 24 hours before each day of testing, to avoid strenuous exercise for 48 hours before testing, and to maintain any existing supplementation regimen throughout the duration for the study. All testing sessions were performed at the same time of day to minimize the effect of circadian rhythms. The investigation was approved by the institutional review board of the University, and all participants provided written informed consent before participation. The study conformed to the principles of World Medical Association´s Declaration of Helsinki.

Experimental design

A within-subjects repeated measures research design was used, whereby kinetics (peak and mean force, peak and mean power, and impulse) were determined during the

PP, PJ and SJ. In addition, lower-body lifting strategy kinematics (dip and thrust displacement and duration) were also calculated from the force-time data. The kinetics were calculated from force platform derived data.

Testing procedures

Participants performed the one repetition maximum (1RM) single assessment protocol during the PP defined by Soriano et al. (2019), which has previously reported a high reliability and low variability in resistance-trained participants (ICC= 0.96; CV = 1.8%) (Soriano et al., 2019). The 1RM test was performed with a maximum of 7 days before the biomechanics assessment. Subsequently, a standardized load of 80% of each individual's previously determined 1RM PP was selected to perform all lifts to remove the impact of load on the kinetics. This load has been identified as the optimal load for maximal power production during the PP in previous research (Lake et al., 2014). The barbell was lifted from squat stands before starting each attempt to minimize fatigue associated with performance of the clean, which precedes the jerk in weightlifting competitions.

For the biomechanics assessment, participants performed a standardized warm up protocol previously described by Lake et al. (2014) and Soriano et al. (2019). This began with 5 minutes of stationary running on a treadmill and continued with 2-3 minutes of upper and lower-body dynamic stretching. The exercise-specific warm up part consisted of one circuit of 10 repetitions of squats, front squats at ¼, ½ and full depth, shoulder press, PP, PJ and SJ, lifting the barbell mass only (20 kg). Subsequently, the specific warm-up included one set of 5 submaximal (50-60% of the maximal perceived effort) repetitions in each exercise (PP, PJ and SJ). Participants then rested for 5 minutes before performing another set of 3 submaximal (70-75% of the maximal perceived effort) repetitions in each exercise. After the warm-up, participants rested for 5 minutes before biomechanics testing commenced as previously specified (Soriano et al., 2019).

During the biomechanics testing, exercise order was randomly assigned to each participant so that they performed 1 set of 3 repetitions of each exercise, starting with either the PP, PJ or the SJ. After each repetition, participants were instructed to put the barbell back in the power rack and rest for 30 seconds to minimize fatigue, and ensure technical proficiency and power maintenance during the PP, PJ and SJ (Comfort et al., 2011b). The technical aspects of the exercises employed (PP, PJ and SJ) are well defined in the literature and the guidelines previously provided were strictly followed to avoid confusion and set appropriate technique standards (Lake et al., 2014; Soriano et al., 2019). Briefly, in the PP the barbell must be pressed upward throughout the full extension of the hips, knees, and ankles, flexion of the shoulders and extension of the elbows, while the feet do not leave the ground. However, during the PJ participants fully extended the hip, knee and ankle joints, accelerating the barbell upward before dropping under the barbell in a ¼ squat, to catch the barbell with elbows and shoulders fully extended overhead. For the SJ, participants followed the same initial instructions as in the PJ but instead of catching the barbell in a ¼ squat, they split their feet fore and aft. Note that contrary to the PP, the feet leave the ground for both the PJ and SJ.

Measurement equipment and data analysis

All tests were performed using standardized barbells and plates (Werksan weights and Olympic bar; Werksan, Moorestown, New Jersey, USA), lifting platforms and power racks (Powerlift, Iowa, USA). During the biomechanics testing, all lifts were performed with participants standing on an in-ground force platform (AMTI, Advanced Medical Technologies Inc, Newton, *Massachusetts*, USA) sampling at 1000 Hz, interfaced with a laptop. Data were collected in Qualisys Trac Manager software and subsequently analyzed using Excel (Microsoft, USA).

The kinetics (dip and thrust peak and mean force, power and impulse), as well as the dip and thrust displacement and duration were derived from vertical force using the methods previously described by Lake et al. (2014) and Soriano et al. (2020) during weightlifting exercises. Data were analyzed using a customized Excel spreadsheet to obtain the kinetics (mean and peak force, mean and peak power and impulse) and phase duration and displacement. Velocity of the COM was obtained by subtracting barbell and body weight (system weight: force averaged over 0.5 to 1.0 s period of pre-exercise standing still) from vertical force to get net force before dividing it by system mass (system weight / acceleration of gravity), and then integrating the product using the trapezoid rule. Mechanical power achieved by displacing system mass was calculated as the product of force and velocity of the COM (Soriano et al., 2020). Impulse was obtained from the area under the net force-time curve during the dip and thrust phases using the trapezoid rule (Lake et al., 2014). To describe the lower-body lifting strategy kinematics underpinning the kinetics of these weightlifting variations (PP, PJ and SJ), COM displacement and the duration of the dip and thrust phases were selected. The dip phase began at the onset of the countermovement and ended at the velocity transition from negative to positive (lowest system COM position). The onset of the countermovement was identified as the instant when vertical force was reduced by a threshold equal to 5 times the standard deviation of the BW (calculated in the weighing phase), as previously suggested (McMahon, Suchomel, Lake, & Comfort, 2018). The post-countermovement transition from negative to positive velocity marked the beginning of the thrust phase which ended at peak velocity, a point common to all three exercises that represents the end of the positive displacement / positive acceleration part of the thrust phase (**Figure**

1). The dip corresponds to the sum of the unweighing and braking phases, whereas the thrust is the rapid propulsion phase via extension of the hips, knees and plantar flexion of the ankles (Soriano et al., 2019). Therefore, dip and thrust displacement were calculated by integrating the velocity-time curve with respect to time, and then phase durations were calculated (Flores et al., 2017; Lake et al., 2014). The repetition where the lifter achieved the highest power production during each weightlifting variation (PP, PJ and SJ), was selected for further analysis along with all dip and thrust kinetics (e.g. peak and mean force, peak and mean power and impulse) related to it, using Excel (Microsoft, USA).

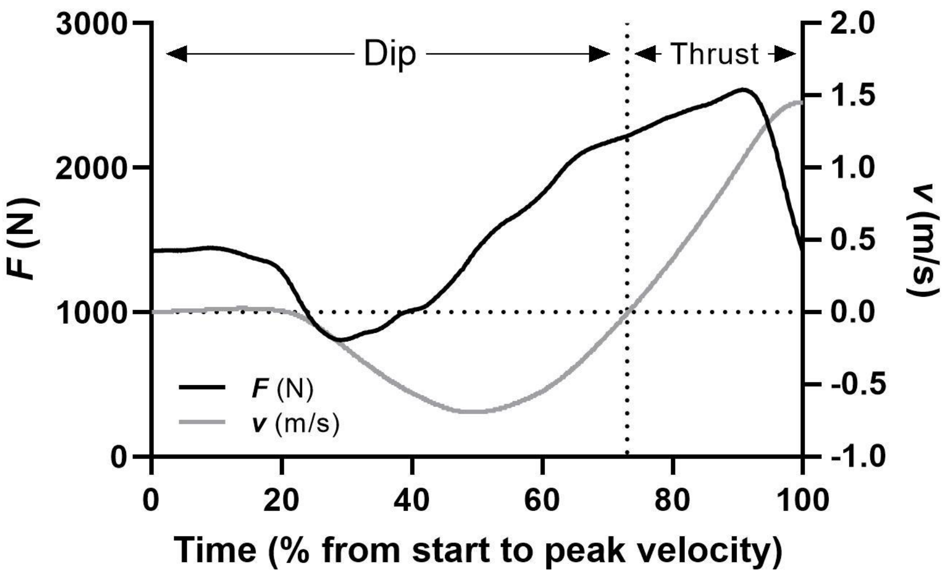

Figure 1. Graphic representation of the force-time and the integrated velocity-time characteristics of the push press exercise performed at 80% of 1RM by a random subject. Force is represented as the system mass (force exerted by the subject plus barbell and body weight). *F* force, v velocity. **Dip** corresponds to the unweighting and braking phases of the lift with negative direction. **Thrust** corresponds to the propulsion phase with positive direction.

Statistical Analyses

All data are presented as mean ± *SD*, where appropriate. Inter-repetition reliability of the force-time characteristics for each exercise variation (PP, PJ and SJ) was determined using the coefficient of variation (CV), intraclass correlation coefficient (ICC; model 3.1) and associated 95% confidence intervals (CI). Intraclass correlation coefficient and associated CI were interpreted based on the recommendations of Koo et al. (2016) where values of the ICC lower bound 95%CI $\leq$ 0.50 is indicative of poor reliability, 0.5 and 0.74 indicate moderate reliability, 0.75 and 0.90 indicate good reliability, and values > 0.90 indicate excellent reliability. A CV <10% was used as a criterion for the minimum acceptable reliability (Baumgartner & Chung, 2001). The reliability analysis was performed by means of a custom spreadsheet (Hopkins, 2000).

After the assumption that data were normally distributed was confirmed using the Shapiro-Wilk's test, a one-way analysis of variance (ANOVA) and Bonferroni post hoc analysis were conducted to determine if there were any significant differences in force-time characteristics between lifts. In addition, lifting strategy kinematics (dip and thrust displacement and time) were also analyzed. An *a priori* alpha level was set at $p \leq 0.05$. Eta squared (η^2) were used to determine the magnitude of the effect independently of the sample size; η^2 has previously been recommended for ANOVA designs (Lakens, 2013), and interpreted based on the recommendations of Cohen (Cohen, 1988) (small < 0.06, medium = 0.06 – 0.14 and large $\geq$ 0.14). All statistical analyses were performed using SPSS version 25.0 for Mac (Chicago, IL, USA).

Results

Shapiro-Wilk test of normality revealed that all data were normally distributed ($p > 0.05$). Intraclass correlation coefficients (and associated CI) revealed a high inter-repetition reliability for all the kinetics (peak and mean force, peak and mean power, and impulse) during the three exercises (PP, PJ, SJ) (**Table 1**). Briefly, reliability was good to excellent for PP dip peak power, PJ dip peak force, dip peak power and dip mean power. Compared to the PP and PJ, the SJ showed lower reliability. SJ dip peak force, thrust mean force, dip peak power, thrust mean power and dip impulse reliability was good to excellent; dip mean power reliability was moderate to good. Similarly, the low %CV confirmed acceptable variability for most of the kinetics for the PP, PJ, and SJ (**Table 1**). However, dip peak power during the PP (CV = 10.8%) and SJ (CV = 10.9%) as well as dip mean power during the SJ (CV = 10.5%) exceeded the previously stablished criterion of CV <10% for minimum acceptable reliability.

Table 1. Inter-repetition reliability of the kinetics during the push press, push jerk and split jerk exercises

Performance variables	Push press		Push jerk		Split jerk	
	ICC	%CV	ICC	%CV	ICC	%CV
Dip PF (N)	0.97	3.00	0.95	4.20	0.93	2.69
(95% CI)	(0.93 – 0.99)	(1.80 – 3.88)	(0.89 – 0.98)	(3.39 – 5.86)	(0.86 – 0.97)	(1.95 – 3.65)
[Interpretation]	Excellent	Acceptable	Good	Acceptable	Good	Acceptable
Thrust PF (N)	0.98	2.69	0.97	3.24	0.97	2.85
(95% CI)	(0.96 – 0.99)	(1.95 – 3.65)	(0.94 – 0.99)	(2.81 – 4.61)	(0.94 – 0.99)	(1.92 – 3.79)
[Interpretation]	Excellent	Acceptable	Excellent	Acceptable	Excellent	Acceptable
Dip MF (N)	0.98	3.04	0.97	3.23	0.98	2.69
(95% CI)	(0.95 – 0.99)	(1.89 – 3.97)	(0.94 – 0.99)	(2.50 – 4.45)	(0.96 – 0.99)	(1.95 – 3.65)
[Interpretation]	Excellent	Acceptable	Excellent	Acceptable	Excellent	Acceptable
Thrust MF (N)	0.99	2.20	0.98	2.42	0.92	3.66
(95% CI)	(0.98 – 1.00)	(1.41 – 2.89)	(0.96 – 0.99)	(1.77 – 3.29)	(0.85 – 0.97)	(5.92 – 6.57)
[Interpretation]	Excellent	Acceptable	Excellent	Acceptable	Good	Acceptable
Dip PP (W)	0.93	10.84	0.94	8.10	0.88	10.90
(95% CI)	(0.86 – 0.99)	(6.96 – 14.25)	(0.88 – 0.97)	(5.51 – 10.80)	(0.77 – 0.95)	(5.21 –13.46)
[Interpretation]	Good	Unacceptable	Good	Acceptable	Good	Unacceptable
Thrust PP (W)	0.98	5.44	0.98	3.24	0.96	4.29
(95% CI)	(0.96 – 0.99)	(4.79 – 7.78)	(0.97 – 0.99)	(1.39 – 3.93)	(0.92 – 0.98)	(5.82 – 7.14)
[Interpretation]	Excellent	Acceptable	Excellent	Acceptable	Excellent	Acceptable
Dip MP (W)	0.95	8.55	0.93	7.72	0.75	10.52
(95% CI)	(0.90 – 0.98)	(6.36 – 11.67)	(0.86 – 0.97)	(5.25 – 10.29)	(0.55 – 0.88)	(8.83 – 14.84)
[Interpretation]	Excellent	Acceptable	Good	Acceptable	Moderate	Unacceptable
Thrust MP (W)	0.97	5.53	0.98	5.53	0.95	5.02
(95% CI)	(0.95 – 0.99)	(3.54 – 7.26)	(0.95 – 0.99)	(3.54 – 7.26)	(0.89 – 0.98)	(4.85 – 7.39)
[Interpretation]	Excellent	Acceptable	Excellent	Acceptable	Good	Acceptable
Dip Imp (N.s)	0.96	9.78	0.95	6.42	0.95	8.68
(95% CI)	(0.91 – 0.98)	(7.43 – 13.43)	(0.91 – 0.98)	(3.61 – 8.19)	(0.89 – 0.98)	(4.81 – 11.04)
[Interpretation]	Excellent	Acceptable	Excellent	Acceptable	Good	Acceptable
Thrust Imp (N.s)	0.98	4.32	0.99	2.54	0.95	3.44
(95% CI)	(0.97 – 0.99)	(3.35 – 5.97)	(0.98 – 1.00)	(1.05 – 3.06)	(0.90 – 0.98)	(4.25 – 5.52)
[Interpretation]	Excellent	Acceptable	Excellent	Acceptable	Good	Acceptable

ICC intraclass correlation coefficient, *CV* coefficient of variation, *CI* confidence interval, *PF* peak force, *MF* mean force, *PP* peak power, *MP* mean power, *Imp* impulse

The results of the one-way ANOVA demonstrated no significant or meaningful differences for the thrust peak (p = 0.84) and mean force (p = 0.87) between the PP (2548 ± 512 N, 2295 ± 453 N, respectively), PJ (2646 ± 520 N, 2373 ± 462 N, respectively) and SJ (2640 ± 528 N, 2368 ± 471 N, respectively) with small effect sizes ($\eta^2 < 0.008$). There were no significant or meaningful differences for the thrust peak (p = 0.83) and mean power (p = 0.83) between the PP (3136 ± 922 W, 1829 ± 475 W, respectively), PJ (3299 ± 987 W, 1934 ± 522 W, respectively) and SJ (3322 ± 904 W, 1906 ± 486 W, respectively) with small effect sizes ($\eta^2 < 0.008$). No significant or meaningful differences (p = 0.95, $\eta^2 = 0.002$) were found when comparing the thrust impulse between exercises (PP, 226 ± 61 N.s; PJ, 233 ± 63 N.s; SJ, 232 ± 60 N.s) (**Figure 2**). Similarly, no significant or meaningful differences were found when comparing the dip peak force (PP, 2325 ± 453 N; PJ, 2428 ± 475 N; SJ, 2424 ± 512 N; p = 0.79), dip mean force (PP, 1988 ± 445 N; PJ, 2013 ± 416 N; SJ, 2017 ± 410 N; p = 0.98), dip peak power (PP, -1152 ± 420 W; PJ, -1213 ± 415 W; SJ, -1199 ± 405 W; p = 0.91), dip mean power (PP, -840 ± 275 W; PJ, -870 ± 282 W; SJ, -858 ± 271 W; p = 0.95) and dip impulse (PP, 99 ± 31 N.s; PJ, 100 ± 31 N.s; SJ, 100 ± 33 N.s; p = 0.99) with small effect sizes ($\eta^2 \leq 0.01$) .

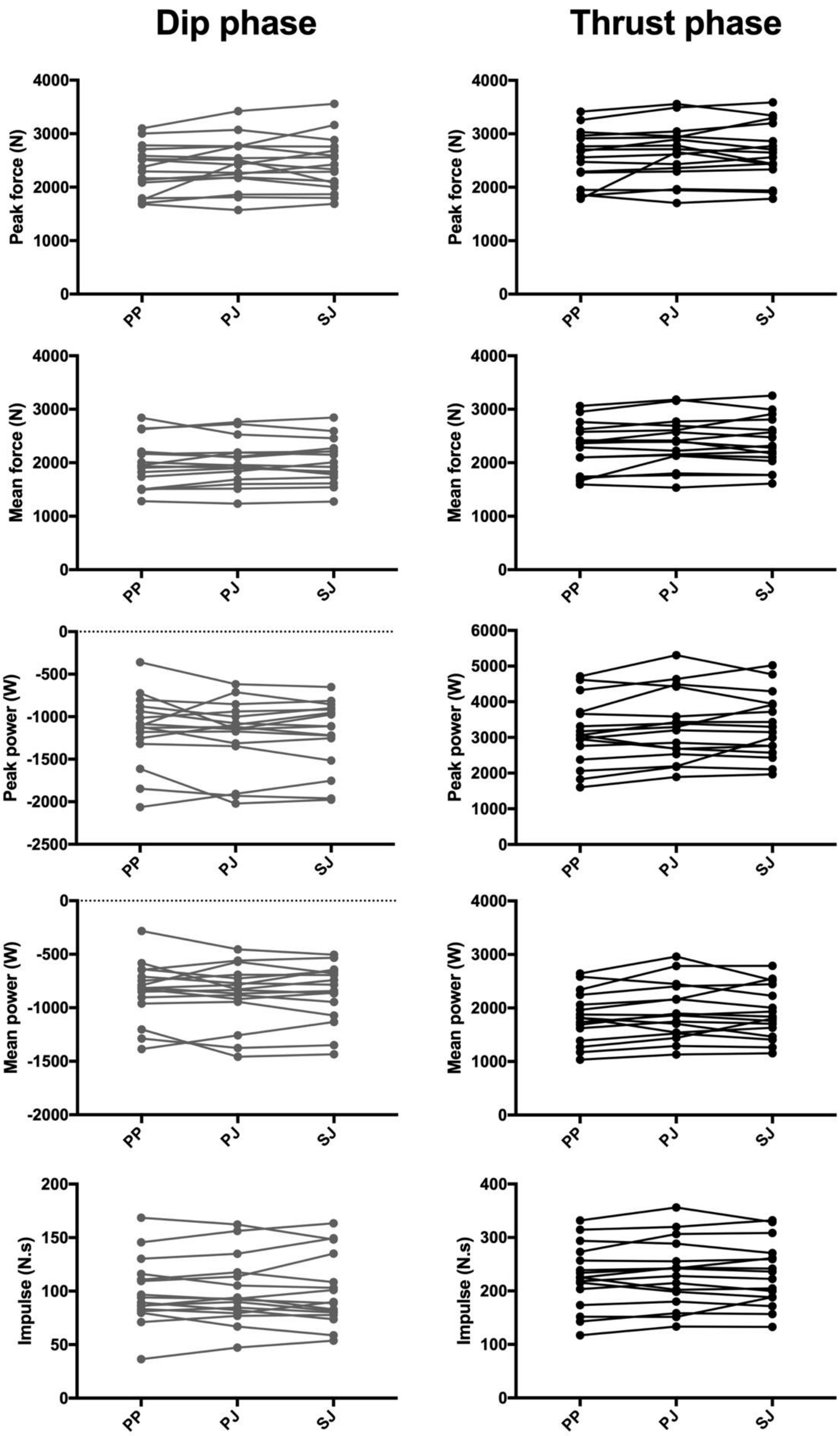

Figure 2. Kinetics recorded in the dip and thrust phases during the push press, push jerk and split jerk. Each circle represents the outcome of one participant in the three exercises. The thin line links the outcomes of the three exercises for each participant. There were no significant ($p > 0.05$) differences in kinetics between the push press, push jerk and split jerk ($p > 0.05$) with small effect sizes ($\eta^2 < 0.01$). *PP* push press, *PJ* push jerk, *SJ* split jerk.

Table 2. Lifting strategy kinematics underpinning kinetic performance variables during the push press, push jerk and split jerk

Lifting strategy kinematics	PP (average)	PJ (average)	SJ (average)	***p* (η^2)**
Dip displacement (m) [range]	0.20 ± 0.05 [0.10 – 0.28]	0.19 ± 0.04 [0.14 – 0.27]	0.20 ± 0.05 [0.13 – 0.27]	**0.98 (0.001)**
Thrust displacement (m) [range]	0.18 ± 0.05 [0.09 – 0.28]	0.19 ± 0.05 [0.10 – 0.28]	0.18 ± 0.04 [0.12 – 0.27]	**0.92 (0.004)**
Dip duration (s) [range]	0.53 ± 0.08 [0.38 – 0.66]	0.52 ± 0.11 [0.33 – 0.76]	0.51 ± 0.13 [0.32 – 0.82]	**0.88 (0.006)**
Thrust duration (s) [range]	0.23 ± 0.05 [0.14 – 0.34]	0.22 ± 0.05 [0.12 – 0.33]	0.22 ± 0.05 [0.14 – 0.34]	**0.93 (0.003)**

PP push press. *PJ* push jerk, *SJ* split jerk

In addition, there were no significant or meaningful differences for the dip (p = 0.98) and thrust (p = 0.92) displacement of the PP (0.20 ± 0.05 m, 0.18 ± 0.05 m, respectively), PJ (0.19 ± 0.04 m, 0.19 ± 0.05 m, respectively) and SJ (0.20 ± 0.05 m, 0.18 ± 0.04 m, respectively) with small effect sizes ($\eta^2 < 0.01$). Similarly, there were no significant or meaningful differences when comparing the dip (p = 0.87) and thrust (p = 0.93) duration of the PP (0.53 ± 0.08 s, 0.23 ± 0.05 s, respectively), PJ (0.52 ± 0.11 s, 0.22 ± 0.05 s, respectively) and SJ (0.51 ± 0.13 s, 0.22 ± 0.05 s, respectively) with small effect sizes ($\eta^2 < 0.01$) (**Table 2**).

Discussion and implications

The findings of this study should aid strength and conditioning coaches during selection of exercises for a structured and periodized training program. Briefly, the results of this study show no significant or meaningful differences in kinetics between the three weightlifting overhead pressing derivatives (PP, PJ and SJ) performed at a standardized load of 80%1RM PP. As hypothesized, these findings may be due to the similarities in the lower-body lifting strategy kinematics for all lifts. Additionally, the inter-repetition reliability was moderate to excellent for all the variables analysed (**Table 1**). It is important to note that although the reliability was questionable for some measures of the dip kinetics (SJ peak power and mean power and PP peak power), the reliability for all measures of the thrust (propulsion) kinetics during the three exercises was good to excellent.

There were no differences in PP, PJ, and SJ peak and mean force. These results are in line with Comfort et al. (Comfort et al., 2011a) who reported no differences between the mid-thigh clean pull and mid-thigh power clean, when performed at a load of 60% 1RM power clean. Similarly, there were no differences for the peak and mean power output between the PP, PJ, and SJ (**Figure 2**), in line with previous results on the kinetics of power clean variations when performed at a fixed load (Comfort et al., 2011b; Suchomel et al., 2014). These lack of differences in kinetics could be explained by the fact that there were no significant differences ($p > 0.88$) in the dip and thrust displacement and time between the PP, PJ and SJ, suggesting that a similar technical execution of the movement pattern may not affect the force-time characteristics and the resulting power generating capacity of weightlifting overhead pressing derivatives.

Researchers recently reported differences in the 1RM performance between the PP (87%), PJ (95%), and SJ (100%) due to the fact that the catch phase enables the lifter to drop underneath the barbell during the PJ and SJ, which reduces the requisite vertical barbell displacement needed to complete each lift (Soriano et al., 2019). In our study, the differences in the subjects' 1RM performances (PP = 85%; PJ = 92%; SJ = 100%) were in line with previous results, and a fixed load of 80% of the 1RM PP was selected for the comparison of the three exercises, resulting in lower relative loads for the PJ (74%) and SJ (68%). Therefore, it may be reasonable to expect differences in kinetics between the three exercises because during the PP the lifter is required to accelerate the system mass across the full range of motion, pressing and locking the barbell overhead without re-flexing the hips, knees and ankles. In contrast, the PJ and SJ do not strictly require an upper-body pressing motion through the entire barbell displacement and also allows the lifter to drop underneath the barbell, where less impulse could be an efficient option to catch the barbell overhead. However, in this study participants were specifically instructed to perform each lift (PP, PJ, and SJ) with maximum effort (‘*push the floor as hard as possible*’) to maximize the force that could be applied to the system in the relatively short contraction time that the lift demands, in line with standardized training practices to maximise intent during exercise performance (Kawamori & Newton, 2006). Then, these findings highlight that even when the load is fixed to a certain percentage of one exercise (80% 1RM PP), practitioners could expect similar kinetics between the PP, PJ and SJ as long as their athletes lift with maximum effort.

Weightlifting overhead pressing derivatives have been compared with exercises with similar lower-body kinematics in previous research (Comfort, Mather, & Graham-Smith, 2013; Comfort et al., 2016; Lake et al., 2014). Comfort et al. (2016) compared the peak power output achieved during the squat jump, mid-thigh power clean and PP across 50, 60 and 70% 1RM in male amateur athletes. Researchers determined that there were no significant differences ($p > 0.05$) between exercises in peak force, rate of force development, and power performed with a standardized load of 60% 1RM power clean (Comfort, et al., 2013). Similarly, Lake et al. (2014) demonstrated no significant differences between PP and jump squat maximum peak power output (7% , $p = 0.08$), impulse applied to the load that maximized peak power (8%, $p = 0.17$) and mean power (13%, $p = 0.91$); however, PP maximum mean power output was significantly greater than the jump squat (~9.5%, $p = 0.03$). Interestingly, Garhammer (1985; 1991) found similarities between snatch and clean second pull power (3004 to 4904 W, 3723 to 6255 W, respectively) with the jerk (4033 to 6953 W), in experienced weightlifters. The lack of significant or meaningful differences may be attributable to the fact that propulsion phase kinematics were similar between exercises, as with this study, therefore resulting in no differences in kinetics (i.e. force, impulse, power). Together, these findings support the notion that weightlifting overhead pressing derivatives such as the PP may be a suitable option to effectively develop rapid lower-body force and power generating capacity. This is because the PP, PJ or SJ present similar lower-body mechanical demands during the propulsion phase compared with other ballistic and weightlifting exercises such as the jump squat, mid-thigh power clean and snatch (Comfort et al., 2013; Garhammer, 1991; Garhammer, 1985).

To our knowledge, this is the first study aimed to compare the kinetics between the main three weightlifting overhead pressing derivatives that could help strength and conditioning coaches to select the most appropriate weightlifting variation for developing lower-body strength and power. However, this study has several limitations that should be addressed in future research. First, there were no highly skilled weightlifters in this study; therefore, as the differences in weightlifting performance are affected by sport group (Soriano et al., 2019), the results of this study should be extrapolated with caution to weightlifters with a high technical proficiency. Second, it is essential to note that the effect of load was removed from this study to focus on the influence of exercise selection purely. Therefore, further research investigating the kinetics and lower-body lifting strategy kinematics of these lifts employing a broader range of loads (i.e. 60, 70, 80, 90% 1RM PP) is guaranteed for comparisons of the PP, PJ, and SJ. Based on previous studies focused on power clean variations, it may be hypothesized that lighter and heavier loads would change the lifting strategy kinematics, and therefore, the resulting kinetics

(Comfort, Jones, & Udall, 2015; Comfort, Udall, & Jones, 2012). Third, in this study the relative load was based on the PP 1RM performance for the comparison of the three exercises, resulting in lower relative loads for the PJ (74%) and SJ (68%); considering that heavier loads can hypothetically be lifted during the PJ and SJ, future research should address the comparison of kinetics and lifting strategy kinematics between the PP, PJ and SJ based using their respective relative loads. This will help strength and conditioning coaches to make evidence-based decisions regarding exercise and load selection to enhance the force-velocity relationship of their athletes (Suchomel, Lake, & Comfort, 2017).

Conclusions

There were no significant or meaningful differences in kinetics between the main weightlifting overhead pressing derivatives when performed at the same standardized load of 80% 1RM PP. In addition, there was a moderate to excellent inter-repetition reliability for the kinetics of the PP, PJ and SJ.

ACKNOWLEDGMENTS

The authors thank the individuals who participated in this investigation. No grant funding was received to support this research, and the authors declare no conflict of interest.

REFERENCES

Baumgartner, T. A., & Chung, H. (2001). Confidence limits for intraclass reliability coefficients. *Measurement in Physical Education and Exercise Science*, 5, 179-188. https://doi.org/10.1207/S15327841MPEE0503_4

Chiu, L. Z. F., & Schilling, B. K. (2005). A primer on weightlifting: from sport to sports training. *Strength and Conditioning Journal*, 27, 42-48. https://doi.org/10.1519/1533-4295(2005)027<0042:apowfs>2.0.co;2

Cohen J. (1988). The analysys of variance and covartiance, 274-288. In *Statistical Power Anaylsis for the Behavioural Science (2nd Edition)*. Mahwahm NJ: Erlbaum, 1988.

Comfort, P., Allen, M., & Graham-Smith, P. (2011a). Comparisons of peak ground reaction force and rate of force development during variations of the power clean. *Journal of Strength and Conditioning Research*, 25, 1235-1239. https://doi.org/10.1519/JSC.0b013e3181d6dc0d

Comfort, P., Allen, M., & Graham-Smith, P. (2011b). Kinetic comparisons during variations of the power clean. *Journal of Strength and Conditioning Research*, 25, 3269-3273. https://doi.org/10.1519/JSC.0b013e3182184dea

Comfort, P., Jones, P. A., & Udall, R. (2015). The effect of load and sex on kinematic and kinetic variables during the mid-thigh clean pull. *Sports Biomechanics*, 14, 139-156. https://doi.org/10.1080/14763141.2015.1025237

Comfort, P., Jones, P., & McMahon, J. (2018). Strength - isometric and dynamic testing, 166-192. *Performance assessment in strength and conditioning* (Routlegde). Milton Park, Abingdon, Oxon: Routledge, London.

Comfort, P., Mather, D., & Graham-Smith, P. (2013). No differences in kinetics between the squat jump, push press and mid-thigh power clean. *Journal Athletic Enhancement*, *2*, 6-7.

Comfort, P., Mcmahon, J. J., & Fletcher, C. (2013). No kinetic differences during variations of the power clean in inexperienced female collegiate athletes. *Journal of Strength and Conditioning Research*, 27, 363-368. https://doi.org/10.1519/JSC.0b013e31825489c6

Comfort, P., Mundy, P. D., Graham-Smith, P., Jones, P. A., Smith, L. C., & Lake, J. P. (2016). Comparison of peak power output during exercises with similar lower-limb kinematics. *Journal of Trainology*, 5, 1-5. https://doi.org/10.17338/trainology.5.1

Comfort, P., Udall, R., & Jones, P. A. (2012). The effect of loading on kinematic and kinetic variables during the midthigh clean pull. *Journal of Strength and Conditioning Research*, 26, 1208-1214. https://doi.org/10.1519/JSC.0b013e3182510827n

Flores, F. J., Sedano, S., & Redondo, J. C. (2017). Optimal load and power spectrum during jerk and back jerk in competitive weightlifters. *Journal of Strength and Conditioning Research*, 31, 809-916. https://doi.org/10.1519/JSC.0000000000001544

Garhammer, J. (1991). A comparison of maximal power outputs between elite male and female weightlifters in competition. *International Journal of Sports Biomechanics*, 7, 3–11.

Garhammer, J (1985). Biomechanical profiles of olympic weightlifters. *International Journal of Sports Biomechanics*, 1, 122-130.

Hackett, D., Davies, T., Soomro, N., & Halaki, M. (2016). Olympic weightlifting training improves vertical jump height in sportspeople: A systematic review with meta-analysis. *British Journal of Sports Medicine*, 50, 865-872. https://doi.org/10.1136/bjsports-2015-094951

Hopkins, W. (2000). Calculations for reliability (Excel spreedsheet). *A New View Stat*.

Hori, N., Newton, R. U., Andrews, W. A., Kawamori, N., Mcguigan, M. R., & Nosaka, K. (2008). Does performance of hang power clean differentiate performance of jumping, sprinting, and changing of direction? *Journal of Strength and Conditioning Research*, 22, 412-418. https://doi.org/10.1519/JSC.0b013e318166052b

Hori, N., Newton, R. U., Nosaka, K., & Stone, M. H. (2005). Weightlifting exercises enhance athletic performance that requires high-load speed strength. *Strength and Conditioning Journal*, 24, 50-55. https://doi.org/10.1519/00126548-200508000-00008

Kawamori, N., & Newton, R. U. (2006). Velocity specificity of resistance training: Actual movement velocity versus intention to move explosively. *Strength and Conditioning*

Journal, 28, 86-91. https://doi.org/10.1519/1533-4295(2006)028[0086:VSORTA]2.0.CO;2

Kelly, J., McMahon, J., & Comfort, P. (2015). A comparison of maximal power clean performances performed from the floor, knee and mid-thigh. *Journal of Trainology*, 3, 53-56. https://doi.org/10.17338/trainology.3.2_53

Koo, T. K., & Li, M. Y. (2016). A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *Journal of Chiropractic Medicine*, 15, 155-163. https://doi.org/10.1016/j.jcm.2016.02.012

Lake, J., Lauder, M., & Dyson, R. (2007). Exploring the biomechanical characteristics of the weightlifting jerk. In *International Society Biomechanics in Sports* (p. 1).

Lake, J. P., Lauder, M. A., & Smith, N. A. (2012). Barbell kinematics should not be used to estimate power output applied to the barbell-and-body system center of mass during lower-body resistance exercise. *Journal of Strength and Conditioning Research*, 26, 1302-1307. https://doi.org/10.1519/JSC.0b013e31822e7b48

Lake, J. P., Mundy, P. D., & 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

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. *Frontiers in Psychology*, 4, 863. https://doi.org/10.3389/fpsyg.2013.00863

McMahon, J. J., Suchomel, T. J., Lake, J. P., & Comfort, P. (2018). Understanding the key phases of the countermovement jump force-time curve. *Strength and Conditioning Journal*, 40, 96-106. https://doi.org/10.1519/SSC.0000000000000375

Soriano, M. A., Suchomel, T., & 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., Kipp, K., Lake, J. P., Suchomel, T. J., Marín, P. J., Sainz De Baranda, M. P., & Comfort, P. (2020). Mechanical power production assessment during weightlifting exercises. A systematic review. *Sports Biomechanics*, 1. 1-27. https://doi.org/10.1080/14763141.2020.1747529

Soriano, M. A., García-Ramos, A., Torres-González, A., Castillo-Palencia, J., Marín, P. J., Sainz de Baranda, P., & Comfort, P. (2019). Comparison of 1-repetition-maximum performance across 3 weightlifting overhead pressing exercises and sport groups. *International Journal of Sports Physiology and Performance*, 15, 862-867. https://doi.org/10.1123/ijspp.2019-0582

Soriano, M. A., García-Ramos, A., Torres-González, A., Castillo-Palencia, J., Marín, P. J., & Comfort, P. (2019). Validity and reliability of a standardized protocol for assessing the one repetition maximum performance during overhead pressing exercises. *Journal of Strength and Conditioning Research*, ahead of print. 10.1519/jsc.0000000000003284

Suchomel, T. J., Comfort, P., & Lake, J. P. (2017). Enhancing the force-velocity profile of athletes using weightlifting derivatives. *Strength and Conditioning Journal*, 39, 10-20. https://doi.org/10.1519/SSC.0000000000000275

Suchomel, T. J., Comfort, P., & Stone, M. H. (2015). 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., Lake, J. P., & Comfort, P. (2017). Load absorption force-time characteristics following the second pull of weightlifting derivatives. *Journal of Strength and Conditioning Research*, 31, 1644-1652. https://doi.org/10.1519/JSC.0000000000001634

Suchomel, T. J., Wright, G. A., Kernozek, T. W., & Kline, D. E. (2014). Kinetic comparison of the power development between power clean variations. *Journal of Strength and Conditioning Research*, 28, 350-360. https://doi.org/10.1519/JSC.0b013e31829a36a3

Turner, A., Comfort, P., McMahon, J., Bishop, C., Chavda, S., Read, P., … Lake, J. (2020). Developing powerful athletes, part 1: mechanical underpinnings. *Strength & Conditioning Journal*, 42, 30-39. https://doi.org/10.1519/SSC.0000000000000543

Figure captions

Figure 1. Graphic representation of the force-time and the integrated velocity-time characteristics of the push press exercise performed at 80% of 1RM by a random participant. Force is represented as the system mass (force exerted by the participant plus barbell and body weight). *F* force, v velocity. **Dip** corresponds to the unweighting and braking phases of the lift, with negative direction. **Thrust** corresponds to the propulsion phase, with positive direction.

Figure 2. Kinetics recorded in the dip and thrust phases during the push press, push jerk and split jerk. Each circle represents the outcome of one participant in the three exercises. The thin line links the outcomes of the three exercises for each participant. There were no significant ($p > 0.05$) differences in kinetics between the push press, push jerk and split jerk with small effect sizes ($\eta^2 < 0.01$). *PP* push press, *PJ* push jerk, *SJ* split jerk.