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Research article

Assessment of asymmetry at different intensities between conventional and paralympic powerlifting athletes

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A R T I C L E I N F O

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A B S T R A C T

Powerlifting competitions require consistent and symmetric lifting of heavy loads and maximal effort, in which, asymmetric lifting results in trial invalidation. Symmetry during this very high intensity movement is determinant to athletes' performance and success in competitions. This study aimed to compare the asymmetry between Conventional Powerlifting athletes (CP) and Paralympic (PP) athletes at intensities of 45 and 80% 1RM before and after a training session. Twenty-two male athletes (11 CP: 29.84 ± 4.21 and 11 PP: 30.81 ± 8.05 years old) participated in this study. Mean Propulsive Velocity (MPV), Maximum Velocity (Vmax) and Power during the concentric and eccentric phases were evaluated at 45%-1RM before and after a training session. For the intensity of 80%-1RM, MPV, Vmax and Power were measured in the first and last series (5

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series of 5 repetitions: 5X5) of a training session. PP athletes demonstrated lower velocity and greater symmetry at 45%-1RM, but higher velocity and less asymmetry at 80%-1RM, when compared to CP. The data indicated that PP athletes tend to be slower at lower intensities, faster at higher intensities in absolute values, and have greater symmetry than CP.

1. Introduction

Strength training (ST), it is widely known by its positive effects in health and performance, particularly in sports involving strength [1]. Powerlifting (PL) is one of these sports modalities that require ST. Coaches, strength and conditioning coaches, and athletes use ST to develop physical capabilities and motor skills to get the highest performance and technique possible in the execution of movements [2,3]. One of the technical requirements (rule) in paralympic powerlifting (PP) competitions is that athletes must maintain symmetry during the Bench Press (BP) execution. Unlikely in conventional powerlifting (CP) if asymmetry is observed during lifting, the movement attempt is not valid [4,5].

Asymmetric movements are characterized when one of the limbs (most of the time the dominant one) reaches a higher level of motor recruitment, muscle activity and adaptation [6]. Excessive asymmetry worsens performance due to movement instability and may lead to a greater risk of injury [7,8]. Paralympic Powerlifting athletes have limitations in the lower limbs, generating instability and possibly compromising bench press (BP) movement execution [9]. Other factors influencing asymmetry is the muscle group, velocity of muscular contraction, joint angle and load applied during training [10,11]. Although studies using BP have evaluated differences in velocity profile and training intensity in the performance of para-athletes, they have not analyzed asymmetries regarding the movement of the bar [12,13].

Asymmetries tend to be affected by exercise intensity, where lower intensities (≅ 50% 1RM) tend not to interfere or produce small asymmetries. Higher loads (≅ 90% 1RM), loads close to our intervention tend to produce greater asymmetries [8,10,14]. On the other hand, another study that evaluated intensities from 40 to 95%, identified greater asymmetries in loads from 60% 1RM. Thus, there seems to be no agreement regarding asymmetries related to intensity [8,10,13–15]. Additionally, Paralympic athletes tend to have greater body asymmetries, and this tends to cause a greater risk of injury [3,6,10] compared to healthy athletes.

Bearing in mind that high intensities are associated with worse asymmetry and accumulation of fatigue during consecutive sets and repetitions, performance is reduced by neuromuscular and metabolic changes, compromising movement symmetry [16,17]. The aim of this study was to compare acute asymmetry at intensities of 45% and 80% 1RM between PP and CP before and after a training session. It was hypothesized that there will be differences in relation to the velocity of displacement of the bar at different intensities in relation to the dominant and non-dominant side between PP and CP athletes.

2. Materials & methods

2.1. Study design

This is a two-week cross-sectional observational study. In the first week, participants were familiarized with equipment and protocols; then, they performed a 1RM test on the bench press. In the second week, participants performed 4 repetitions at 45%-1RM, five sets of five repetitions (5X5) at 80%-1RM, and a second set at 45%-1RM. Throughout the study, there was a minimum interval of 72 h between assessments, whether familiarization or testing (Fig. 1).

2.2. Sample

The sample of this study consisted of 22 males (11 CP and 11 PP), aged between 18 and 35 years. The sample size was calculated using the open-source software G*Power® (Version 3.0; Berlin, Germany), an “F family statistic (ANOVA)” was adopted considering a standard $\alpha < 0.05$, $\beta = 0.80$ and the effect size of 1.33 found for Rate of Force Development (RFD) in powerlifting athletes [13]. Thus, it was possible to estimate a sampling power of 0.80, with a minimum sample of eight subjects per group, which suggests that the sample

Moments		Procedures and tests (Monday)				Other Days
Week 1 (Familiarization) and 1RM Test)	◎		Test (1RM)		◎	Rest
Week 2 (Tests and Intervention)	◎	Pre-Tests 45% 1RM	Intervention 80% 1RM (5 Sets of 5 Repetition)	Post-Tests 45% 1RM	◎	Rest

Fig. 1. Experimental study design. Legend: 1RM: One Maximum Repetition.

size in the study would have statistical strength for the type of research. Athletes from the CP group had more than 18 months of training and athletes from the PP group had more than 24 months of experience. Additionally, the PP athletes have experience competing at the national level (International Paralympic Committee (IPC), 2022) and were ranked among the top ten in their respective categories. Six athletes have a malformation in the lower limbs (arthrogryposis); one with sequelae due to poliomyelitis; four with amputations; one with spinal cord injury (below T8) due to an accident. All participants were volunteers and signed a free and informed consent form in accordance with resolution 466/2012 of the National Research Ethics Committee (CONEP) of the National Health Council (NHC). We also followed the ethical principles expressed in the Declaration of Helsinki (1964, revised in 1975, 1983, 1989, 1996, 2000, 2008, and 2013) of the World Medical Association. This study was approved by the Research Ethics Committee of the Federal University of Sergipe, number CAAE: 2.637.882 (approval date: May 7, 2018). Sample characteristics is displayed in Table 1.

2.3. Instruments/procedures

Paralympic athletes' body mass was measured with athletes seated using a wheelchair accessible electronic and digital scale with an electronic platform (Micheletti, São Paulo, Brazil). The scale maximum weight capacity is 300 kg and dimensions of 1.50 m per 1.50 m. Bench press exercise was performed in an official bench (2.10 m in length, Eleiko, Halmstad, Sweden) and Olympic barbell (220 cm in total length, weight 20 kg) approved by the International Paralympic Committee (IPC, 2022). Conventional powerlifter's body mass was measured using a digital platform scale Filizola 2002 (Filizola, São Paulo, Brazil) calibrated from 0 to 150 kg, with an accuracy of 0.1 kg, was used to measure the weight in kilograms (kg).

The number of repetitions during BP was recorded using three iPhones (12 cameras, Apple Inc., Cupertino, California, USA). Videos were recorded with a resolution of 4k and 30 frames per second (fps) [18]. The iPhones were connected on tripods at approximately 1 m from the ground. The cameras were arranged, as follows: two laterally in relation to the bar at a distance of 1.5 m and another at 3.0 m from the reflective markers. The cameras were distributed equidistantly from the center to the end of the bar, forming a perpendicular angle to the plane of movement. The velocity of the bar was tracked in different positions (right side and left side), as previously described and validated [10,19].

The videos were processed frame-by-frame at 30 fps and analyzed using the open-source software Kinovea version 0.9.5 (Free Software Foundation Inc., Boston, Massachusetts, USA) [20]. The software calibration was made by positioning three 1.0 m sticks vertically with cylindrical reflective markers in each side. Reflective markers were also placed in the center, and at the left and right end of the bar to ensure measurement consistency. Reflective markers were used to facilitate the visualization of markings. The evaluations were manual, and this would be justified by the low speed used in the Powerlifting. In addition to the mentioned calibration, the length of the Olympic bar was used. This allowed to minimize the error, with a maximum error of 2.47 mm. In order to minimize the error, the moment and image used for the calibration procedure occurred when the athlete positioned the bar, removing it from the hack, and was ready to start the movement. This procedure allowed the software to convert the digital pixel measurements into centimeters (cm) [10,21].

The velocity of the eccentric and concentric phases of the BP was obtained from each iPhone during the four repetitions at 45% of 1RM, and the 5 $\times$ 5 at 80% of 1RM before and after CP [22]. The first and last repetitions were considered for data analysis purposes. The recorded mean velocity for the eccentric phase was considered the moment in which athletes lowered the bar toward their chests. The final moment of the eccentric phase was considered when athletes stopped the bar on their chest. The concentric phase was considered as starting in the ascending component of the movement, ending with full elbow extension [4]. All frames were computed according to the movement required by the IPC (bar stops on the chest) [4] (Fig. 2).

The 1RM test was performed on the first visit. Each participant started their attempt with a weight that they believed could be lifted only once with maximum effort. If required, weight increments were added until the participant reached their maximum load that could be lifted once. If the athlete could not perform the movement, 2.4 to 2.5% of the load used in the test was subtracted [13]. Participants rested between 3 and 5 min between trials [11] and 72 h before the second visit. In this second visit, the athletes warmed up in the bench press for approximately 10 min before data collection [17]. Then, the athletes performed a series of 4 repetitions at an intensity of 45% of 1RM. After resting, they performed a 5X5 protocol at 80% of 1RM with 3 to 5 min break between bouts. Next, another series of 4 repetitions at 45% of 1RM was executed at the end. This initial and final series at 45% of 1RM was used as before and after comparisons [23].

Table 1
Sample characteristics.

	Conventional Powerlifting (CP)	Paralympic Powerlifting (PP)
Age (years)	29.84 ± 4.21	30.81 ± 8.05
Body weight (kg)	78.52 ± 7.95	70.00 ± 16.13
Experience (years)	1.81 ± 0.41	2.84 ± 1.31
1RM Bench Press Test (kg)	112.49 ± 17.71	122.02 ± 38.06
1RM/Body mass	1.40 ± 0.61[a]	1.71 ± 0.42[a]

[a] Values above 1.4 in the Bench Press, would be considered elite athletes [13].

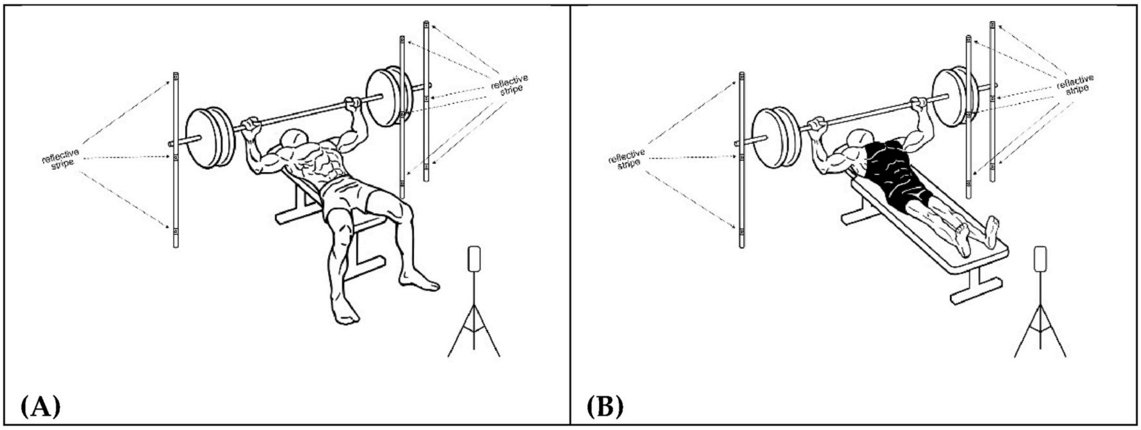

Fig. 2. Position for Bench Press analyses, (A) Conventional Powerlifting, and (B) Para-lympic Powerlifting.

2.4. Statistics

Descriptive statistics were performed considering measures of central tendency, mean ± standard deviation (X±SD), and 95% confidence interval (95% CI). The Shapiro Wilk test was used to verify the normality of the variables, considering the sample size. For the validation of repeated measurements, Mauchly's sphericity test was used and, when necessary, the Greenhouse-Geisser correction was applied. A Two-way ANOVA for repeated measures determined the differences between sides (dominant and non-dominant), moments (before and after), and paralympic powerlifters and conventional powerlifters. For the intensities of 45% and 80% of 1RM, for each of the repetitions during the eccentric and concentric phases. Bonferroni's post hoc test was performed to detect statistically significant differences. The significance level adopted was $p < 0.05$. The effect size was calculated using $\eta 2p$ = partial eta squared, (small effect ≤0.05, medium effect 0.05 to 0.25, high effect 0.25 to 0.50 and very high effect >0.50) [24]. Statistical analyses were performed using the computerized Statistical Package for the Social Sciences (SPSS 25.0) (IBM, New York, USA).

3. Results

The kinetics of conventional (CP) and paralympic powerlifting (PP) at mean velocity before and after (45% 1RM) and series 1 and 5 (80% 1RM), with non-dominant and dominant sides during the eccentric and concentric phases are displayed in Figs. 3 and 4. For 45% 1RM, four repetitions were evaluated and for 80% 1RM, five repetitions were evaluated in the first series (Set 1) and in the last series (Set 5).

Tables 2 and 3 show the dominant and non-dominant side values before and after 45% of 1RM during the eccentric and concentric phases.

Tables 4 and 5 show the dominant and non-dominant side values in the eccentric and concentric phases regarding series 1 and 5 at 80% of 1RM.

4. Discussion

The main objective of our study was to analyze asymmetry at intensities of 45% and 80% 1RM between PP and CP athletes after a training session. The results indicated that there are differences in symmetry between CP and PP, with intensities of 45 and 80%. PP athletes showed less asymmetry than CP. Regarding the intensity of 45% of 1RM, there were statistically significant asymmetry effects

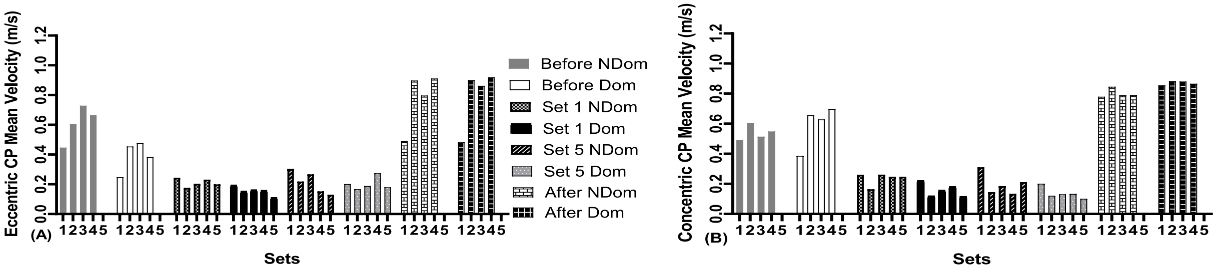

Fig. 3. Kinetics of Conventional Powerlifting (PC) at mean velocity before and after the 5 × 5 protocol (45% 1RM) and series 1 and 2 (80% 1RM), with non-dominant and dominant sides during the eccentric **(A)** and concentric **(B)** phases. CP: Conventional Powerlifting; NDom: Non-Dominant; Dom: Dominant. **Note:** Before and after, only four repetitions were evaluated.

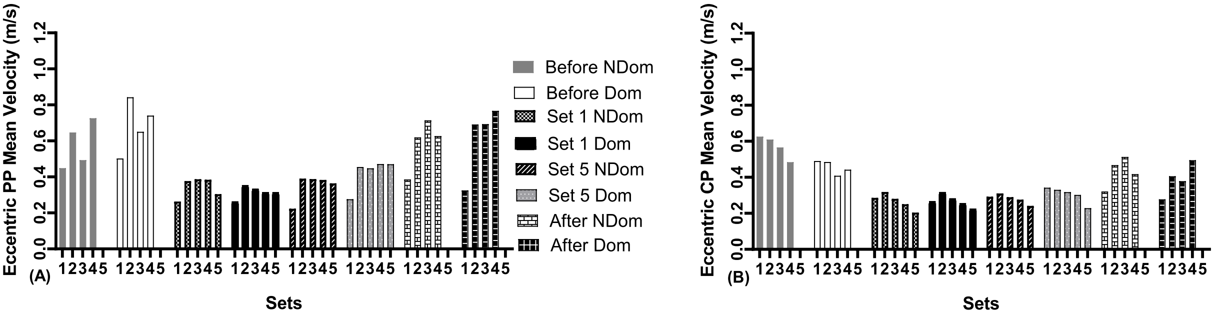

Fig. 4. Kinetics of Paralympic Powerlifting (PP) at mean velocity before and after the 5 × 5 protocol (45% 1RM) and series 1 and 2 (80% 1RM), with non-dominant and dominant sides during the eccentric **(A)** and concentric **(B)** phases. PP: Paralympic Powerlifting; NDom: Non-Dominant; Dom: Dominant. **Note:** Before and after, only four repetitions were evaluated.

Table 2
Eccentric Mean Velocity of the dominant and non-dominant limbs with 45% of 1RM, before and after the 5 × 5 protocol (Mean ± SD, and CI 95%).

	Before		After		*p*	η2p
	Non-Dominant	Dominant	Non-Dominant	Dominant		
Repetition 1	0.26 ± 0.31	0.31 ± 0.36	0.25 ± 0.15c	0.21 ± 0.17d	"a" *p = 0.009	*0.322
PP	(0.05–0.46)	(0.64–0.55)	(0.14–0.34)	(0.95–0.32)	"b" *p = 0.034	
CP	0.45 ± 0.18b	0.25 ± 0.23a,b	0.48 ± 0.16c	0.49 ± 0.16a,d	"c" #p = 0.013	#0.219
	(0.32–0.56)	(0.09–0.40)	(0.37–0.59)	(0.38–0.60)	"d" #p = 0.005	
Repetition 2	0.47 ± 0.37	0.41 ± 0.19a	0.26 ± 0.24c	0.29 ± 0.15a,d	"a" *p = 0.033	*0.657
PP	(0.22–0.72)	(0.29–0.54)	(0.10–0.43)	(0.19–0.39)	"b" *p = 0.004	
CP	0.61 ± 0.33	0.45 ± 0.39b	0.90 ± 0.30c	0.90 ± 0.22b,d	"c" #p = 0.001	#0.121
	(0.38–0.83)	(0.19–0.71)	(0.69–1.10)	(0.75–1.05)	"d" #p < 0.001	
Repetition 3	0.49 ± 0.57	0.39 ± 0.34	0.47 ± 0.38b	0.30 ± 0.22c	"a" *p = 0.033	*0.268
PP	(0.10–0.87)	(0.17–0.62)	(0.21–0.72)	(0.15–0.45)	"b" #p = 0.007	#0.109
CP	0.48 ± 0.41	0.48 ± 0.41a	0.80 ± 0.26b	0.86 ± 0.30a,c	"c" #p < 0.001	
	(0.41–1.05)	(0.20–0.75)	(0.62–0.97)	(0.66–1.06)		
Repetition 4	0.27 ± 0.26c	0.33 ± 0.18	0.35 ± 0.26d	0.54 ± 0.32e	"a" *p = 0.031	*0.255
PP	(0.10–0.52)	(0.21–0.45)	(0.18–0.53)	(0.32–0.75)	"b" *p = 0.001	#0.340
					"c" #p = 0.024	
CP	0.66 ± 0.35a,c	0.38 ± 0.36b	0.91 ± 0.20a,d	0.92 ± 0.17b,e	"d" #p < 0.001	
	(0.43–0.90)	(0.14–0.63)	(0.78–1.04)	(0.80–1.04)	"e" #p < 0.001	

$p < 0.05$ (ANOVA). η2p = partial eta square (small effect ≤0.05, medium effect 0.05 to 0.25, high effect 0.25 to 050, and very high effect (>050). * Intraclass, # Interclass. PP: Paralympic Powerlifters; CP: Conventional Powerlifters.

Table 3
Concentric Mean Velocity of the dominant and non-dominant limbs 45% of 1RM, before and after the 5 × 5 protocol (Mean ± SD, and CI 95%).

	Before		After		*p*	η2p
	Non-Dominant	Dominant	Non-Dominant	Dominant		
Repetition 1	0.63 ± 0.48	0.49 ± 0.27	0.32 ± 0.15c	0.28 ± 0.28d	"a" *p = 0.005	*0.851
PP	(0.30–0.95)	(0.31–0.67)	(0.22–0.42)	(0.09–0.47)	"b" *p = 0.003	
CP	0.49 ± 0.29a	0.39 ± 0.30b,c	0.78 ± 0.12a,c	0.85 ± 0.18b,d	"c" #p < 0.001	#0.056
	(0.30–0.69)	(0.19–0.59)	(0.70–0.86)	(0.73–0.98)	"d" #p < 0.001	
Repetition 2	0.61 ± 0.46	0.48 ± 0.25	0.48 ± 0.25b	0.41 ± 0.32c	"a" *p = 0.034	*0.595
PP	(0.30–0.92)	(0.32–0.65)	(0.32–0.65)	(0.19–0.62)	"b" #p = 0.003	#0.134
CP	0.61 ± 0.31	0.66 ± 0.40a	0.85 ± 0.14b	0.88 ± 0.15a,c	"c" #p = 0.001	
	(0.39–0.82)	(0.39–0.92)	(0.75–0.94)	(0.78–0.98)		
Repetition 3	0.57 ± 0.41	0.41 ± 0.20	0.51 ± 0.37b	0.38 ± 0.28b,c	"a" *p = 0.047	*0.336
PP	(0.28–0.84)	(0.27–0.54)	(0.26–0.76)	(0.19–0.56)	"b" #p = 0.047	#0.247
CP	0.51 ± 0.40a	0.63 ± 0.64	0.79 ± 0.21a	0.88 ± 0.23c	"c" #p = 0.006	
	(0.24–0.78)	(0.19–1.05)	(0.64–0.93)	(0.72–1.03)		
Repetition 4	0.27 ± 0.26	0.33 ± 0.18	0.35 ± 0.26b	0.54 ± 0.32	"a" *p = 0.035	*0.220
PP	(0.10–0.45)	(0.21–0.45)	(0.18–0.53)	(0.32–0.75)	"b" #p < 0.001	#0.033
CP	0.66 ± 0.35a	0.38 ± 0.36	0.91 ± 0.20a,b	0.92 ± 0.17		
	(0.43–0.90)	(0.14–0.63)	(0.78–1.04)	(0.80–1.04)		

$p < 0.05$ (ANOVA). η2p = partial eta square (small effect ≤0.05, medium effect 0.05 to 0.25, high effect 0.25 to 050, and very high effect (>050). * Intraclass, # Interclass. PP: Paralympic Powerlifters; CP: Conventional Powerlifters.

Table 4
Eccentric Mean Velocity of the dominant and non-dominant limbs at 80% of 1RM, regarding sets 1 and 5 (Mean ± SD, and CI 95%).

	Set 1		Set 5		*p*	η2p
	Non-Dominant	Dominant	Non-Dominant	Dominant		
Repetition 1						
PP	0.26 ± 0.09 (0.21–0.32)	0.26 ± 0.05 (0.22–0.30)	0.22 ± 0.09 (0.16–0.28)	0.28 ± 0.16 (0.17–0.38)	"a" *p = 0.007	*0.483
CP	0.24 ± 0.14 (0.15–0.34)	0.20 ± 0.18 (0.08–0.32)	0.30 ± 0.16a (0.20–0.41)	0.18 ± 0.09a (0.12–0.24)		
repetition 2						
PP	0.38 ± 0.15a (0.27–0.48)	0.35 ± 0.08b (0.30–0.41)	0.39 ± 0.12c (0.31–0.47)	0.45 ± 0.19d (0.33–0.58)	"a" #p = 0.031 "b" #p = 0.004	#0.223
CP	0.18 ± 0.15a (0.07–0.28)	0.15 ± 0.14b (0.06–0.24)	0.22 ± 0.14c (0.13–0.31)	0.17 ± 0.16d (0.06–0.27)	"c" #p = 0.027 "d" #p = 0.007	
repetition 3						
PP	0.39 ± 0.17 (0.27–0.50)	0.33 ± 0.13a,c (0.25–0.42)	0.39 ± 0.13b (0.30–0.47)	0.45 ± 0.13a,b (0.36–0.53)	"a" *p = 0.003 "b" *p = 0.007	*0.097
CP	0.20 ± 0.16 (0.10–0.31)	0.16 ± 0.17c (0.05–0.28)	0.27 ± 0.19 (0.14–0.39)	0.19 ± 0.14 (0.09–0.28)	"c" #p = 0.002	#0.166
repetition 4						
PP	0.38 ± 0.21 (0.24–0.53)	0.31 ± 0.12a,d (0.23–0.40)	0.38 ± 0.16c,b (0.27–0.49)	0.47 ± 0.19a,b (0.34–0.60)	"a" *p = 0.012 "b"*p = 0.002	*0.364
CP	0.23 ± 0.16 (0.13–0.34)	0.16 ± 0.14d (0.06–0.25)	0.15 ± 0.11c (0.07–0.23)	0.27 ± 0.38 (0.02–0.53)	"c" #p = 0.012 "d" #p = 0.007	#0.073
repetition 5						
PP	0.30 ± 0.17a (0.19–0.41)	0.31 ± 0.14a,b,c (0.22–0.40)	0.36 ± 0.18d (0.25–0.48)	0.47 ± 0.21b,e (0.33–0.61)	"a,b" *p = 0.001 "c" #p = 0.006	*0.210 #0.467
CP	0.20 ± 0.20 (0.06–0.34)	0.11 ± 0.12c (0.03–0.19)	0.13 ± 0.09d (0.07–0.19)	0.18 ± 0.16e (0.07–0.28)	"d" #p = 0.008 "e" #p = 0.018	

$p < 0.05$ (ANOVA). η2p = partial eta square (small effect ≤0.05, medium effect 0.05 to 0.25, high effect 0.25 to 050 and very high effect (>050). * Intraclass, # Interclass. PP: Paralympic Powerlifters; CP: Conventional Powerlifters.

Table 5
Concentric Mean Velocity of the dominant and non-dominant limbs at 80% of 1RM, regarding sets 1 and 5 (Mean ± SD, and CI 95%).

	Set 1		Set 5		*p*	η2p
	Non-Dominant	Dominant	Non-Dominant	Dominant		
Repetition 1						
PP	0.29 ± 0.12 (0.20–0.37)	0.26 ± 0.11 (0.19–0.34)	0.29 ± 0.10a (0.23–0.36)	0.34 ± 0.10b,a (0.27–0.41	"a" *p = 0.006 "b" *p = 0.003	*0.688 #0.982
CP	0.26 ± 0.19 (0.14–0.38)	0.22 ± 0.16 (0.11–0.33)	0.31 ± 0.18 (0.19–0.43)	0.20 ± 0.11b (0.13–0.27)		
Repetition 2						
PP	0.32 ± 0.06a (0.28–0.36)	0.32 ± 0.11b (0.24–0.39)	0.31 ± 0.05c (0.27–0.35)	0.33 ± 0.09d (0.27–0.39)	"a" #p = 0.006 "b" #p = 0.007	#0.119
CP	0.16 ± 0.10a (0.10–0.23)	0.12 ± 0.14b (0.03–0.21)	0.14 ± 0.08c (0.09–0.20)	0.12 ± 0.09d (0.06–0.18)	"c" #p < 0.001 "d" #p < 0.001	
Repetition 3						
PP	0.28 ± 0.07 (0.23–0.33)	0.28 ± 0.10 (0.22–0.34)	0.29 ± 0.08 (0.24–0.34)	0.32 ± 0.11b (0.25–0.39)	"a" *p = 0.041 "b" #p = 0.002	*0.352 #0.190
CP	0.26 ± 0.18a (0.14–0.38)	0.16 ± 0.18a (0.04–0.28)	0.18 ± 0.10 (0.12–0.25)	0.13 ± 0.11b (0.06–0.20)		
Repetition 4						
PP	0.25 ± 0.07 (0.21–0.29)	0.25 ± 0.06 (0.21–0.30)	0.28 ± 0.10a (0.21–0.34)	0.30 ± 0.14b (0.21–0.40)	"a" #p = 0.022 "b" #p = 0.006	#0.166
CP	0.25 ± 0.24 (0.09–0.41)	0.18 ± 0.19 (0.05–0.31)	0.13 ± 0.10a (0.07–0.20)	0.13 ± 0.10b (0.07–0.20)		
Repetition 5						
PP	0.20 ± 0.05a (0.17–0.24)	0.22 ± 0.08a,b (0.17–0.28)	0.24 ± 0.11 (0.17–0.31)	0.23 ± 0.10c (0.16–0.29)	"a" *p = 0.033 "b" #p = 0.047	*0.336 #0.296
CP	0.25 ± 0.19 (0.12–0.38)	0.12 ± 0.15b (0.02–0.21)	0.21 ± 0.18 (0.09–0.33)	0.10 ± 0.09c (0.04–0.16)	"b" #p = 0.019	

$p < 0.05$ (ANOVA). η2p = partial eta square (small effect ≤0.05, medium effect 0.05 to 0.25, high effect 0.25 to 050 and very high effect (>050). * Intraclass, # Interclass. PP: Paralympic Powerlifters; CP: Conventional Powerlifters.

between pre and post training. Our results contradict previous studies that did not report significant differences in asymmetry with lower loads, i.e., 45% 1RM [8,10,14]. The 45% 1RM was selected based on its accuracy in demonstrating the influence on velocity kinetics. This workload is easily sustained and tolerated by the athletes, representing an average velocity of approximately 1 m/s [25, 26], which would not promote greater asymmetry, and in this case, it seems that the asymmetry would have been influenced and increased by the 5X5 protocol.

In the eccentric phase, it was noticed significant levels of asymmetry within and between groups, in which, the first repetition showed the highest level of asymmetry. According to previous investigations, the highest levels of asymmetry occur during the concentric phase, being very small or non-existent in the eccentric phase [10,27]. Our study showed greater asymmetry both in the eccentric and concentric phases for the conventional athletes, the same not occurring for the Paralympics, who tended to be more symmetrical. This finding can be partially explained by the differences in neurological characteristics of muscle tension between the concentric and eccentric phases. In the eccentric phase, there is a lower level of motor unit activity, which can result in a loss of stability during movement [28].

The PP group was able to maintain more symmetric repetitions than the PC group, in relation to the movement phases and repetitions (Tables 2 and 3). This result is contrary to the initial observations in which the PP, considering the asymmetry, in some cases in the lower limbs, due to atrophies and amputations, could lead to instabilities, and even to greater asymmetries, which was not detected in our results. Due to these same asymmetries in the lower limbs, we initially tended to indicate that para-athletes would be more asymmetrical than powerlifters [9]. On the other hand, in powerlifting, considering the high loads lifted, it was expected that athletes would have more neural adaptations, exhibiting higher levels of motor learning, muscle activation, and force production, which could have a positive impact on symmetry [29–31].

Allied to the above, another study, involving several sports, found important levels of asymmetry, leading to the hypothesis that fatigue due to training tends to alter metabolic and neuromuscular factors, and this alteration tends to increase asymmetry [16,17]. The consequence of fatigue and the possible increase in fatigue would promote an increase in dominance and, therefore, greater asymmetry over time, as a consequence of fatigue resulting from training, which could decrease performance and increase the risk of injuries. Fatigue would tend to promote asymmetry in terms of force generation between the sides, which could increase joint instability [32,33]. Adding to this factor, accumulated fatigue tends to compromise sports performance, and may generate movement asymmetries. That is, even at submaximal intensities, there would be a reduction in speed and strength, with a tendency to increase asymmetry [17].

Fatigue tends to be associated with loss of velocity, and therefore fatigue tends to increase asymmetry. When evaluating loads at 45% and 65% of 1RM, no differences were found in the metabolic indicators of fatigue, with differences only in the lifting velocity [17]. Corroborating these data, studies that applied an acute intervention in very low volume (only one series of 5 RM or a single series of 1RM) did not find significant results in relation to asymmetry [10,15]. These findings are contrary to our study, where conventional athletes, even at the beginning of the intervention, presented greater asymmetry than the PP. And the conventional athletes, when they were submitted to consecutive series in high intensity, presented worse symmetry between the first and the last repetition, mainly in the concentric phase (Table 3).

Our study, as far as we know, is the first to compare the asymmetry between PP and CP, demonstrating that even with a load of 45% 1RM, fatigue could interfere with symmetry, even with the low intention that tends to be easily moved and tolerated [25]. Thus, after a training session, possibly due to fatigue, the asymmetry indices showed important differences. However, the PP athletes were more symmetrical than the CP. This could perhaps be explained by the fact that the PP rules are more restrictive, which would promote adaptation to training [4]. Furthermore, despite the possible instability generated by lower limb limitations in the PP group, they had lower levels of asymmetry when compared to the CP group. These findings indicate that adaptations to the rules of the sport, and the training of athletes according to the rules, tend to promote adaptations in relation to the technique, with a consequent decrease in asymmetry during movement, whether with greater loads or higher intensities.

With higher loads (80% of 1RM), PP athletes had less asymmetries than CP athletes, but with lower movement speed. A possible explanation for the lower asymmetry of the PP, when compared to the CP, would be related to the rules of the Paralympic sport, which tend to be more restrictive in terms of validating the movements. Thus, in competitions, only symmetrical movements are considered valid. In other words, training for sports normally tends to focus on technique, requiring symmetrical movements, promoting adaptation in the PP, with consequent greater symmetry in movement, aimed at competitions [3,33].

In a study with conventional powerlifting (CP) athletes, performing the bench press, beginners and elite powerlifters were evaluated. Muscle activation was evaluated by electromyography, and loads of 35–100% of 1RM were used. The results indicated that elite athletes tend to apply less force with lower loads (35–55% of 1RM) and the opposite would occur with higher loads (55–85% 1RM) [34]. On the other hand, when assessing asymmetries with greater intensities, and with an explanation focused on adaptation in terms of rules and competitions, PP athletes, despite having greater asymmetries when compared with lower loads, still tend to be less asymmetrical than CP athletes [3,10]. Another study compared muscle activity in the bench press with loads of 85% and 100% of 1RM. The triceps brachii, pectoralis major, and anterior deltoid muscles were evaluated. Two types of bench press were performed, one assisted and the other not, and there were asymmetries mainly in uncontrolled exercises [35,36], reaffirming that at higher intensities asymmetries tend to increase.

Some points regarding Powerlifting training must be emphasized. The work tends to be unassisted since in competitions movements are performed without any kind of assistance [3,4]. This tends to provide even greater adaptation with a tendency towards a decrease in asymmetries, combined with the rules that tend to limit asymmetries, both in the PP and in the CP. However, in people with disabilities, the aetiology of muscle asymmetry has not yet been fully studied, and may or may not be associated with disability [37,38]. This would be explained, since the eligibility criteria in the PP happen according to the functional classification of the athlete, being considered eligible or not for the modality [3]. Thus, it seems that especially with higher loads, PP athletes have less asymmetry and Paralympic weightlifting training seems to be a good possibility for people with disabilities in terms of promoting better symmetry.

However, some limitations must be considered in this study. The sample size was small. Therefore, the current results should be interpreted with caution. The athletes were instructed to perform the lifts as quickly as possible, a factor that tends to be related to increased fatigue. There was no velocity control in the eccentric phase, which could interfere with the results. Diet, sleep, use of any ergogenic agent or any day-to-day activity were not controlled in the present study, with the control through interview only in terms of some type of illicit ergogenic. In this way, it is emphasized that more studies investigating the subject must be carried out in order to fill in the gaps, better describing the phenomenon, helping athletes and coaches in the construction of better training programs.

5. Conclusions

Our study pointed to the need to better assess the effect of training and intensity on asymmetry. Both in PP and CP, higher loads provided greater asymmetries. Furthermore, with lower loads, it seems that fatigue tends to provide greater asymmetries, both in Paralympic and healthy athletes. This, taking into account that with 45% 1RM, asymmetry was evaluated before and after the 5X5 protocol, after training there was a trend of greater asymmetries in both groups. Another important finding of our study was that PP athletes tend to have less asymmetries than CP athletes, both with lower and higher loads. However, the PP had lower speeds than the CP athletes. In this sense, the study presents important findings, indicating that PP athletes are more symmetrical than CP, which tends to be an adaptation to the sport and its rules. Previous studies have already indicated that PP athletes tend to be stronger than CP athletes, and our study indicated that PP athletes tend to be more symmetrical than CP athletes.

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Institutional Review Board statement

The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board and approved by the Human Research Ethics Committee of the Federal University of Sergipe (UFS), under Statement Number 2637882/2018.

Informed consent statement

Informed consent was obtained from all subjects involved in the study.

Production notes

Author contribution statement

Rafael Luiz Mesquita Souza, Felipe J. Aidar: Wrote the paper; Performed the experiments.
Leonardo dos Santos, Rodrigo Villar: Performed the experiments.
Jefferson Lima de Santana, Ana Filipa Silva, Dihogo Gama de Matos, Hadi Nobari: Contributed reagents, materials, analysis tools or data.
Roberto Carvutto, Filipe Manuel Clemente, Luca Poli, Georgian Badicu: Analyzed and interpreted the data.
Felipe J. Aidar, Gianpiero Greco, Francesco Fischetti, Stefania Cataldi: Conceived and designed the experiments.

Data availability statement

Data will be made available on request.

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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