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Reliability of kinematic parameters of power snatch from recreationally-trained weightlifters

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Abstract
Introduction. The Olympic weightlifting movements (snatch, clean and jerk) and their variations (snatch and clean deadlift, high pull, etc.) have been widely used in order to improve performance in many sports, but there are no normative data, nor data on reliability of kinematic parameters for power snatch from recreational weightlifters. Aim of Study. This study aimed to quantify the reliability and the minimal detectable change of kinematic parameters from bar displacement during a power snatch movement in non-professional (i.e., recreationally trained) weightlifters. Material and Methods. Sixteen healthy (13 male), trained, but non-competitive weightlifters, volunteered to participate in this study. Each volunteer performed 2 power snatches at 60% of their RM. The barbell path was recorded using a high-speed camera and the data was processed off-line to obtain barbell position coordinates. Elapsed time to complete the movement, trunk and knee position at catching, the kinematic parameters from horizontal and vertical bar displacements, vertical velocity and acceleration were obtained for each of the 5 movement phases (1st pull, transition, 2nd pull, turnover and drop). Descriptive data, intraclass coefficient correlation (ICC) and minimal detectable change (MDC) from each studied variable were obtained and presented. Results. Our results indicated low to excellent reliability for studied variables, with the initial phases of the lift (i.e., 1st pull, transition and 2nd pull) displaying better reliability, while the later phases of the movement (turnover and drop) exhibited poorer reliability for a majority of variables. Conclusions.The presented data, with a comprehensive description of normative data obtained from the power snatch of recreational weightlifters could help coaches to evaluate power snatch performance as a conditioning tool for recreational athletes.

KEYWORDS: kinematics, biomechanics, Olympic weightlifting, explosive force.

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Introduction

The Olympic weightlifting movements (snatch, clean and jerk) and their variations (snatch and clean deadlift, high pull, etc.) have been widely used in order to improve performance in many sports [2, 12, 22] and in functional fitness programs [25]. Although it requires a long time to acquire the necessary skills to perform the movements with a proper technique, this modality of training has been shown to be effective in improving lower limb power, speed and agility [20].

Olympic weightlifting training (OWT) has gained increased popularity in recent years, especially among recreational fitness enthusiasts, influenced by the growing popularity of mixed modality training (MMT) [6, 15, 18], and the evidence of its safety for non-professional people [21]. Yet, future studies should aim to evaluate long-term effects of weightlifting interventions on the cardiovascular and hemodynamic system [21]. Notably, the increase of adherence to OWT by recreational athletes is a challenge for coaches, since professional weightlifters have a more complete understanding of the athletic lifestyle [21], including awareness that a proper movement technique may promote better performance and ensure safety.

The use of kinematic data is proposed as an effective, safe and low-cost method to guide weightlifting training programs for professional and recreational weightlifters [5, 11, 24]. Data from the barbell displacement, obtained through video capture and their analysis with appropriate software have been widely used to improve the snatch technique [5, 16, 24]. Nevertheless, studies investigating the reliability and the minimal detectable change (MDC) from power snatch kinematics are scarce, even though these statistical parameters (i.e., reliability and MDC) are usually a part of a larger investigative study [23]. Notwithstanding, knowledge of reliability and MDC from kinematic parameters obtained from power snatch of non-professional weightlifters could guide coaches and sport scientists to monitor the effect of OWT routines.

In this context, the present study aimed to quantify the reliability and the MDC of kinematic parameters from bar displacement during a power snatch movement in non-professional (i.e., recreationally trained) weightlifters.

Methods

Experimental approach to the problem

To obtain normative data of kinematic parameters, describing both joint position (knee and hip) and barbell displacement parameters from a power snatch executed by non-professional weightlifters.

Sample

Sixteen healthy volunteers (13 male) participated in this study (age: 25 ± 3 years; height: 172.7 ± 7 cm; body mass: 81.6 ± 10.8 kg; power snatch: 80.8 ± 10.6 kg) and with at least 1 year of experience in Olympic weightlifting, training at least 3 times a week, but without competitive purposes. All participants were informed about the objectives and gave their informed written consent to participate in the study, which was approved by the local research ethics committee (protocol #: 3.425.388).

Procedures

Each volunteer performed two repetitions of a power snatch at 60% of the one repetition maximum (1RM) reported by each volunteer. The self-reported 1RM was based on the best performance at a standard 1RM test (i.e., 3-6 attempts with a 3- to 5-minute interval between each attempt) obtained in their last (~4 week) training cycle. A minimum interval of 2 minutes was given between attempts. The 60% of 1RM was chosen, because it was used in a previous study involving the kinematic analysis [9] and since it corresponds to a load that can confidently be lifted for multiple repetitions, as is often prescribed in MMT programs.

The volunteers were instructed to follow the training routine one day before the data recording, but avoiding any excessive volume. Before the data recording, volunteers carried out a dynamic warm-up consisting by dynamic stretches, 15 power snatch trials with a weighted barbell (20 kg) only, 10 trials with 30% of 1RM, and 5 trials with 60% of 1RM. The power snatch attempts were recorded using a high-speed GoPro® Hero 5 Black (GoPro Inc., USA) digital camera operating at 60 Hz. The camera was placed 5 m from the volunteers and perpendicular to the right side of the sagittal plane. Aiming to obtain the two-dimensional position coordinates of the barbell path in the sagittal plane, the right end was tracked to obtain the position coordinates. The tracking of the barbell path was analyzed using the Kinovea® v0.8.26 software (www.kinovea.org).

A standard box (height = 0.60 m) was used as the reference to calibrate the barbell position coordinates and the coordinate origin was set at the start position of the barbell. With respect to the axes, the data was adjusted as the positive and negative values of the x-axis representing the forward and backward motions of the barbell, respectively, while the positive values of the y-axis represent the vertical upward motions of the barbell. There was no guarantee that the barbell movement would be symmetric. However, the right barbell end was analyzed as the representative point of the barbell trajectory in the present study, as indicated by Nagao et al. [17].

The coordinate values were smoothed using a recursive fourth-order low-pass Butterworth filter at 6 Hz, as used by Kipp and Harris [14]. To obtain the data on barbell kinematics, the lift phases from the power snatch were defined according to the barbell trajectory as described previously [8, 14, 17]: 1) the 1st pull phase (from the start position to the most backward position, when the knees achieve or are close to the maximum extension for the first time); 2) the transition phase (from the end of the first 1st pull phase until the maximum knee flexion, where the volunteer adopts the power position); 3) the 2nd pull phase (from the end of the transition to the peak vertical velocity of the barbell); 4) the turnover phase (from the end of the second pull phase to the maximum height of the barbell path); and 5) the drop phase (from the end of the turnover phase to the catch position).

The elapsed time to complete the movement (i.e., from the start position to the catch position) was recorded, together with the elapsed time to complete each studied phase of movement (i.e., 1st pull, transition, 2nd pull, turnover, drop). The elapsed time in each phase was also normalized by the total time to complete the movement. The trunk and knee angles were measured at the catch position. The horizontal and vertical barbell displacements were recorded for each phase. The horizontal displacement was also measured as done by Winchester et al. [24], obtaining DxL (the horizontal displacement from the most forward position to the catch position), DxT (the horizontal displacement from the start position to the catch position), Dx2 (the horizontal displacement from the start position to the beginning of the 2nd position) and DxV (the horizontal displacement from the 2nd pull position to the most forward position). Mean and peak vertical velocity ($m \cdot s^{-1}$) and vertical acceleration ($m \cdot s^{-2}$) were also recorded from each phase.

Statistical analysis

Descriptive data from each studied variable (joint angle at the catch, elapsed time, barbell displacement, mean and peak velocity and acceleration) are reported as means and the respective 95% confidence interval [95% CI], standard deviation, minimum, maximum, median and 25 and 75 percentiles. The reliability of the kinematic parameters was determined from the ICCs by means of the two-way model (ICC2,1 – a two-way repeated-measures analysis of variance) [19]. The reliability was defined as 'excellent' for ICC values between 0.80 and 1.00, 'good' between 0.60 and 0.80, and 'low' when <0.60, as proposed by Shrout and Fleiss [19]. The ICC and the respective 95% CI were recorded. The error in an individual's score at 1 point in time was estimated by multiplying the standard error of mean (SEM) by the z value for the 90% and 95% confidence level (z value = 1.64 and 1.96 for 90% and 95%, respectively). This value was then multiplied by the square root of 2 (accounting for the measurement error on 2 test sessions) to estimate the MDC at the 90% and 95% confidence levels.

Results

All the recorded attempts were successful. The analysis of knee angle at the catch position demonstrated good reliability (ICC = 0.77 [0.48-0.91]), while for the trunk angle the reliability was low (ICC = 0.59 [0.16--0.82]). The mean angle for the knee flexion was 77.33º and the MDC90 and MDC95 were 10.27º and 12.27º, respectively. For the trunk angle the mean angle was 78.36º and the MDC90 and MDC95 were 7.60º and 9.09º, respectively (Table 1).

The analysis of the duration of each snatch phase indicated a low to excellent reliability. The duration of the 1st pull was the phase with the greatest reliability (ICC = 0.90 [0.76-0.96]) and the drop phase exhibited the lowest reliability (ICC = 0.50 [0.05-0.78]), for the 2nd pull, transition and turnover phases the ICC [95% CI] was 0.86 [0.66-0.95], 0.64 [0.26-0.85] and 0.63 [0.25-0.84]. The total time demanded to complete the task exhibited an excellent reliability (ICC = 0.82 [0.57--0.93]) (Figure 1). When normalized, the demanded time in each phase also ranged from low to excellent (Figure 1).

The mean of total time demanded to complete the power snatch was 1.49 seconds [95% CI = 1.43-1.55] and the MDC90 and MDC95 were 0.18 and 0.22 seconds, and 38.70% [36.48-40.93] of this time was spent in the 1st pull, 7.82 [7.09-8.55] in transition, 16.87 [14.79-18.95] in 2nd pull, 29.83 [27.52-32.14] in turnover and 6.77 [4.95-8.59] in the drop phase. The MDC90 and MDC95 of each phase are presented in Table 1.

The kinematic analysis was based on horizontal (Table 2, Figure 2) and vertical bar displacement parameters (Tables 3-5, Figures 2-4). A greater horizontal bar displacement was observed at the 2nd pull (0.10 m [0.09-0.12]) and turnover phases (0.14 m [0.12-0.15]), and the MDC90 and MCD95 of these were 0.046, 0.055 and 0.06, 0.07 m, respectively. DxL (0.17 m [0.16--0.18]) and DxV (0.10 m [0.09-0.12]) also exhibited horizontal bar displacement of min. 10 cm. The MDC90 and MDC95 ranged from 0.01/0.02 m for the transition phase to 0.09/0.11 m for DxT. All the studied kinematic data from horizontal bar displacement are presented in Table 2. The ICC for horizontal bar displacement ranged from low (ICC = 0.05 [–0.44-0.50]) for the 1st pull, good for transition (ICC = 0.74 [0.44-0.89]), the 2nd pull (ICC = 0.79 [0.52-0.92]), DxT (ICC = 0.73 [0.41-0.89]) and Dx2 (ICC = 0.72 [0.40-0.88]), while

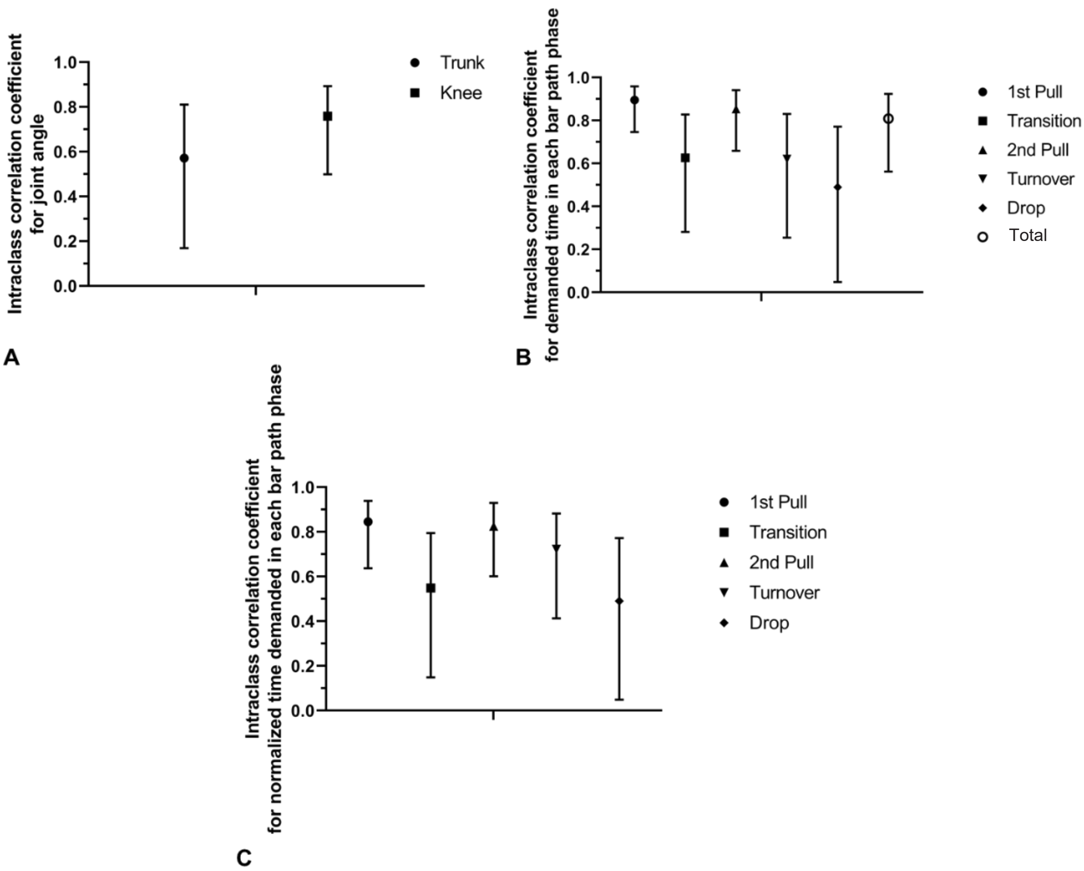

Figure 1. Intraclass correlation coefficient and its respective 95% confidence intervals between power snatch attempts. (A) Trunk and knee angles at the catching the bar; (B) Duration of each phase; (C) Percentual duration of each phase of power snatch

Table 1. Descriptive parameters for trunk and knees angles at catching, and the duration (in seconds and normalized [%]) of each phase of power snatch attempts

Variable/ Phase	Attempt	Mean	95% CI	SD	Min	Max	Median	25-75 Percentile	MDC90	MDC95
Angle at catching the bar										
Trunk	first	77.22	74.07-80.37	6.33	67.00	94.00	75.50	72.00-82.00	10.27	12.27
	second	77.44	73.68-81.20	7.55	68.00	93.00	77.00	71.00-82.00		
	grouped	77.33	75.00-79.65	6.87	67.00	94.00	76.00	72.00-82.00		
Knee	first	78.28	74.40-82.16	7.80	64.00	90.00	78.50	75.00-85.00	7.60	9.09
	second	78.44	75.51-81.38	5.90	68.00	88.00	79.00	74.00-83.00		
	grouped	78.36	76.05-80.67	6.82	64.00	90.00	78.50	74.50-84.00		
Duration of phase (s)										
1st Pull	first	0.59	0.51-0.67	0.16	0.32	1.13	0.56	0.53-0.63	0.12	0.14
	second	0.59	0.50-0.68	0.17	0.30	1.12	0.61	0.48-0.65		
	grouped	0.59	0.53-0.65	0.17	0.30	1.13	0.57	0.53-0.64		

Transition	first	0.12	0.10-0.14	0.03	0.08	0.18	0.12	0.10-0.13	0.06	0.07
	second	0.12	0.09-0.14	0.05	0.07	0.22	0.10	0.08-0.13		
	grouped	0.12	0.10-0.30	0.04	0.07	0.22	0.10	0.08-0.13		
2nd Pull	first	0.24	0.20-0.28	0.08	0.13	0.47	0.23	0.18-0.30	0.07	0.08
	second	0.26	0.22-0.30	0.08	0.12	0.47	0.27	0.18-0.32		
	grouped	0.25	0.22-0.28	0.08	0.12	0.47	0.25	0.18-0.31		
Turnover	first	0.45	0.40-0.51	0.11	0.32	0.70	0.42	0.37-0.52	0.13	0.16
	second	0.44	0.39-0.48	0.09	0.33	0.62	0.41	0.37-0.47		
	grouped	0.44	0.41-0.48	0.09	0.32	0.70	0.41	0.37-0.51		
Drop	first	0.10	0.06-0.14	0.09	0.00	0.27	0.12	0.00-0.17	0.14	0.16
	second	0.10	0.06-0.14	0.08	0.00	0.23	0.10	0.03-0.17		
	grouped	0.10	0.06-0.14	0.08	0.00	0.23	0.10	0.03-0.17		
Total	first	1.49	1.40-1.58	0.18	1.27	2.05	1.44	1.38-1.57	0.18	0.22
	second	1.49	1.39-1.58	0.19	1.20	2.05	1.45	1.38-1.58		
	grouped	1.49	1.43-1.55	0.18	1.20	2.05	1.45	1.38-1.58		
Duration of phase (%)										
1st Pull	First	38.69	35.48-41.91	6.46	23.75	54.84	38.74	35.79-41.56	5.87	7.02
	Second	38.72	35.29-42.15	6.89	23.08	54.03	38.80	34.02-42.27		
	Grouped	38.70	36.48-40.93	6.58	23.08	54.84	38.74	35.28-41.91		
Transition	First	8.04	7.06-9.01	1.96	4.85	11.76	8.29	6.32-9.41	3.31	3.96
	Second	7.60	6.41-8.78	2.38	4.21	13.40	7.00	6.17-9.20		
	Grouped	7.82	7.09-8.55	2.15	4.21	13.40	7.41	6.29-9.29		
2nd Pull	First	16.25	13.20-19.30	6.13	9.41	35.00	15.03	10.87-19.59	6.63	7.92
	Second	17.49	14.38-20.60	6.25	8.05	35.90	17.07	14.29-19.59		
	Grouped	16.87	14.79-18.95	6.14	8.05	35.90	16.20	12.72-19.59		
Turnover	First	30.35	26.67-34.03	7.40	17.74	41.75	28.50	25.00-38.82	8.16	9.76
	Second	29.32	26.15-32.48	6.37	18.55	40.48	29.51	25.00-31.82		
	Grouped	29.83	27.52-32.14	6.82	17.74	41.75	28.72	25.00-36.46		
Drop	First	6.66	3.86-9.46	5.63	0.00	17.39	7.16	0.00-9.57	8.76	10.47
	Second	6.88	4.26-9.49	5.25	0.00	14.29	7.45	1.61-10.87		
	Grouped	6.77	4.95-8.59	5.37	0.00	17.39	7.45	0.81-10.75		

it was excellent for DxV (ICC = 0.84 [0.62-0.94]). The ICC values and its respective 95% CI are presented in Figure 2A.

The total vertical bar displacement (from the ground to the catch position) was 1.47 m [1.43-1.51], the reliability was excellent (ICC = 0.94 [0.84-0.98]) and with a small MDC90 (0.07 m) and MDC95 (0.08 m). The height of the 1st pull was 0.35 m [0.32-0.38], with an excellent reliability (ICC = 0.88 [0.71-0.95]) and small MDC90 (0.06 m) and MDC95 (0.07 m). The unique parameter obtained from the vertical bar displacement with low reliability was the turnover (ICC = 0.57 [0.15-0.81]), with 0.45 m [0.42-0.48] of mean displacement and MDC90 (0.14 m) and MDC95 (0.16 m) corresponding

Table 2. Descriptive parameters from horizontal displacement of the bar for each phase of power snatch attempts

Horizontal displacement (m)										
Variable/ Phase	Attempt	Mean	95% CI	SD	Min	Max	Median	25-75 Percentile	MDC90	MDC95
1st Pull	first	0.03	0.02-0.03	0.01	0.02	0.05	0.03	0.02-0.04	0.03	0.04
	second	0.03	0.02-0.04	0.02	0.01	0.09	0.03	0.03-0.04		
	grouped	0.03	0.03-0.04	0.01	0.01	0.09	0.03	0.02-0.04		
Transition	first	0.02	0.01-0.03	0.01	0.00	0.05	0.02	0.01-0.03	0.01	0.02
	second	0.02	0.01-0.02	0.01	0.00	0.04	0.02	0.01-0.03		
	grouped	0.02	0.02-0.03	0.01	0.00	0.05	0.02	0.01-0.03		
2nd Pull	first	0.11	0.08-0.12	0.04	0.06	0.23	0.09	0.08-0.13	0.046	0.055
	second	0.10	0.08-0.12	0.05	0.03	0.19	0.10	0.08-0.15		
	grouped	0.10	0.09-0.12	0.04	0.03	0.23	0.10	0.08-0.13		
Turnover	first	0.14	0.11-0.16	0.05	0.08	0.24	0.13	0.10-0.17	0.06	0.07
	second	0.14	0.12-0.16	0.04	0.07	0.20	0.14	0.11-0.17		
	grouped	0.14	0.12-0.15	0.04	0.07	0.24	0.12	0.10-0.17		
Drop	first	0.02	0.01-0.02	0.02	0.00	0.06	0.01	0.00-0.03	0.03	0.04
	second	0.02	0.01-0.02	0.02	0.00	0.05	0.01	0.00-0.03		
	grouped	0.02	0.01-0.02	0.02	0.00	0.06	0.01	0.00-0.03		
Dx2	first	–0.02	–0.036 - –0.006	0.03	–0.08	0.04	–0.02	–0.04-0.00	0.04	0.05
	second	–0.03	–0.05 - –0.01	0.04	–0.11	0.04	–0.03	–0.05-0.00		
	grouped	–0.02	–0.036 - –0.013	0.03	–0.11	0.04	–0.02	–0.05-0.00		
DxL	first	0.17	0.15-0.19	0.04	0.10	0.25	0.16	0.13-0.20	0.06	0.08
	second	0.17	0.15-0.19	0.03	0.12	0.24	0.17	0.14-0.20		
	grouped	0.17	0.16-0.18	0.04	0.10	0.25	0.16	0.14-0.20		
DxT	first	–0.05	–0.09 - –0.007	0.08	–0.21	0.09	–0.05	–0.08-0.03	0.09	0.11
	second	–0.06	–0.10 - –0.03	0.07	–0.19	0.08	–0.08	–0.12 - –0.02		
	grouped	–0.06	–0.08 - –0.03	0.08	–0.21	0.09	–0.05	–0.12 - –0.02		
DxV	first	0.10	0.08-0.13	0.05	0.01	0.23	0.09	0.07-0.13	0.045	0.054
	second	0.10	0.08-0.13	0.05	0.02	0.19	0.11	0.07-0.15		
	grouped	0.10	0.09-0.12	0.05	0.01	0.23	0.10	0.07-0.14		

to approximately 33.3% of mean displacement. Transition (ICC = 0.66 [0.30-0.86]), the 2nd pull (ICC = 0.78 [0.50-0.91]) and drop (ICC = 0.79 [0.44-0.93]) exhibited good reliability. Despite the good reliability, the MDC90 and MDC95 of transition, the 2nd pull and drop were relatively high, representing approximately 30 to 35% of the mean displacement of the 2nd pull (0.51 m) and more than 50% of mean displacement of the transition and drop phases (Table 3). The ICC [95% CI] of vertical bar displacement from each phase are presented in Figure 2B.

The mean and peak velocity from vertical bar displacement are presented in Table 4. The greater mean and peak velocity were achieved at the 2nd pull phase. The reliability was excellent (ICC ranging from 0.74 to 0.89 for mean velocity and 0.76 to 0.91 for peak

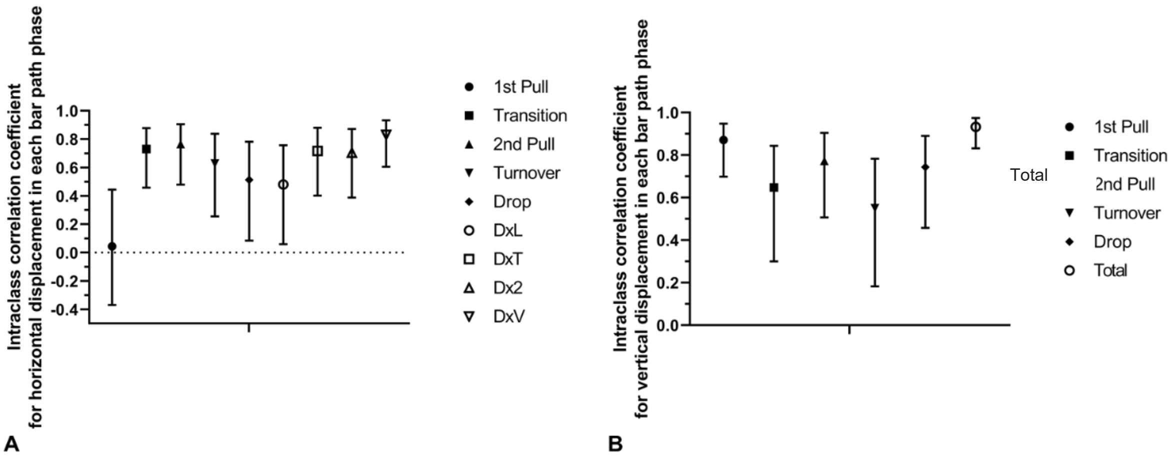

Figure 2. Intraclass correlation coefficient and its respective 95% confidence intervals between power snatch attempts. (A) Horizontal displacement in each phase of power snatch; (B) Vertical displacement in each phase of power snatch

Table 3. Descriptive parameters from vertical displacement of the bar for each phase of power snatch attempts

Vertical displacement (m)										
Variable/ Phase	Attempt	Mean	95% CI	SD	Min	Max	Median	25-75 Percentile	MDC90	MDC95
1st Pull	first	0.36	0.32-0.39	0.07	0.15	0.43	0.37	0.34-0.41	0.06	0.07
	second	0.34	0.30-0.38	0.08	0.12	0.45	0.35	0.32-0.40		
	grouped	0.35	0.32-0.38	0.07	0.12	0.45	0.36	0.32-0.41		
Transition	first	0.17	0.14-0.19	0.06	0.09	0.27	0.15	0.12-0.23	0.08	0.09
	second	0.15	0.12-0.17	0.06	0.07	0.25	0.15	0.10-0.18		
	grouped	0.16	0.14-0.17	0.06	0.07	0.27	0.15	0.11-0.20		
2nd Pull	first	0.49	0.42-0.56	0.14	0.30	0.85	0.48	0.38-0.53	0.15	0.18
	second	0.53	0.46-0.60	0.14	0.28	0.90	0.53	0.45-0.57		
	grouped	0.51	0.47-0.56	0.14	0.28	0.90	0.50	0.43-0.57		
Turnover	first	0.46	0.42-0.49	0.07	0.32	0.62	0.47	0.40-0.51	0.14	0.16
	second	0.44	0.39-0.49	0.11	0.19	0.58	0.50	0.39-0.51		
	grouped	0.45	0.42-0.48	0.09	0.19	0.62	0.47	0.40-0.51		
Drop	first	0.01	0.001-0.01	0.01	0.00	0.05	0.00	0.00-0.01	0.02	0.02
	second	0.01	0.002-0.02	0.02	0.00	0.07	0.01	0.00-0.01		
	grouped	0.01	0.004-0.01	0.01	0.00	0.07	0.00	0.00-0.01		
Total	first	1.47	1.41-1.53	0.12	1.23	1.62	1.51	1.38-1.57	0.07	0.08
	second	1.47	1.40-1.53	0.12	1.25	1.65	1.50	1.36-1.56		
	grouped	1.47	1.43-1.51	0.12	1.23	1.65	1.50	1.36-1.56		

velocity) for all parameters, except for the mean and peak velocity from the turnover phase, which exhibited a low and good reliability (ICC = 0.34 [–0.15-0.70] mean velocity; ICC = 0.64 [0.26-0.85] peak velocity), and the drop phase, which exhibited a low reliability (ICC = 0.25 [–0.39-0.71] for peak velocity). Considering

Table 4. Descriptive parameters of mean and peak vertical velocity during vertical displacement of the bar for each phase of power snatch attempts

Variable/ Phase	Attempt	Mean	95% CI	SD	Min	Max	Median	25-75 Percentile	MDC90	MDC95
Mean velocity (m·s^{-1})										
1st Pull	first	0.64	0.57-0.71	0.14	0.27	0.84	0.66	0.57-0.74	0.21	0.25
	second	0.63	0.53-0.74	0.21	0.27	1.21	0.59	0.51-0.69		
	grouped	0.64	0.57-0.70	0.17	0.27	1.21	0.63	0.53-0.72		
Transition	first	1.38	1.20-1.55	0.36	0.70	1.98	1.39	1.19-1.66	0.28	0.34
	second	1.34	1.14-1.54	0.40	0.37	1.97	1.35	1.13-1.53		
	grouped	1.36	1.23-1.48	0.37	0.37	1.98	1.39	1.16-1.61		
2nd Pull	first	2.08	1.98-2.17	0.19	1.66	2.42	2.09	2.00-2.23	0.23	0.28
	second	2.09	1.97-2.21	0.24	1.51	2.46	2.07	1.96-2.26		
	grouped	2.08	2.00-2.15	0.21	1.51	2.46	2.07	1.97-2.23		
Turnover	first	1.00	0.91-1.09	0.18	0.70	1.25	1.01	0.83-1.18	0.40	0.48
	second	0.98	0.85-1.10	0.25	0.50	1.41	1.00	0.87-1.20		
	grouped	0.99	0.91-1.06	0.21	0.50	1.41	1.00	0.85-1.18		
Drop	first	–0.05	–0.08 - –0.02	0.06	–0.23	0.02	–0.05	–0.09-0.00	0.07	0.08
	second	–0.07	–0.10 - –0.03	0.07	–0.29	0.00	–0.05	–0.10 - –0.01		
	grouped	–0.06	–0.08 - –0.03	0.07	–0.29	0.00	–0.05	–0.10-0.00		
Peak velocity (m·s^{-1})										
1st Pull	first	1.20	1.03-1.36	0.33	0.42	1.74	1.22	1.05-1.48	0.24	0.28
	second	1.16	0.99-1.34	0.36	0.36	1.74	1.13	1.02-1.37		
	grouped	1.18	1.06-1.30	0.34	0.36	1.74	1.17	1.02-1.44		
Transition	first	1.59	1.40-1.77	0.38	0.82	2.22	1.57	1.36-1.82	0.37	0.44
	second	1.56	1.35-1.76	0.41	0.67	2.21	1.52	1.28-1.87		
	grouped	1.57	1.44-1.70	0.39	0.67	2.22	1.54	1.35-1.84		
2nd Pull	first	2.39	2.31-2.47	0.17	2.11	2.73	2.42	2.28-2.51	0.21	0.25
	second	2.42	2.31-2.51	0.20	2.05	2.83	2.42	2.26-2.56		
	grouped	2.40	2.34-2.46	0.18	2.05	2.83	2.42	2.27-2.51		
Turnover	first	2.34	2.24-2.44	0.20	1.91	2.74	2.40	2.22-2.46	0.33	0.39
	second	2.36	2.22-2.49	0.27	1.77	2.78	2.40	2.19-2.58		
	grouped	2.35	2.27-2.43	0.24	1.77	2.78	2.40	2.20-2.49		
Drop	first	–0.02	–0.03 - –0.01	0.03	–0.09	0.02	–0.02	–0.03-0.00	0.06	0.07
	second	–0.02	–0.04 - –0.01	0.03	–0.08	0.03	–0.02	–0.03-0.00		
	grouped	–0.02	–0.03 - –0.01	0.03	–0.09	0.03	–0.02	–0.03-0.00		

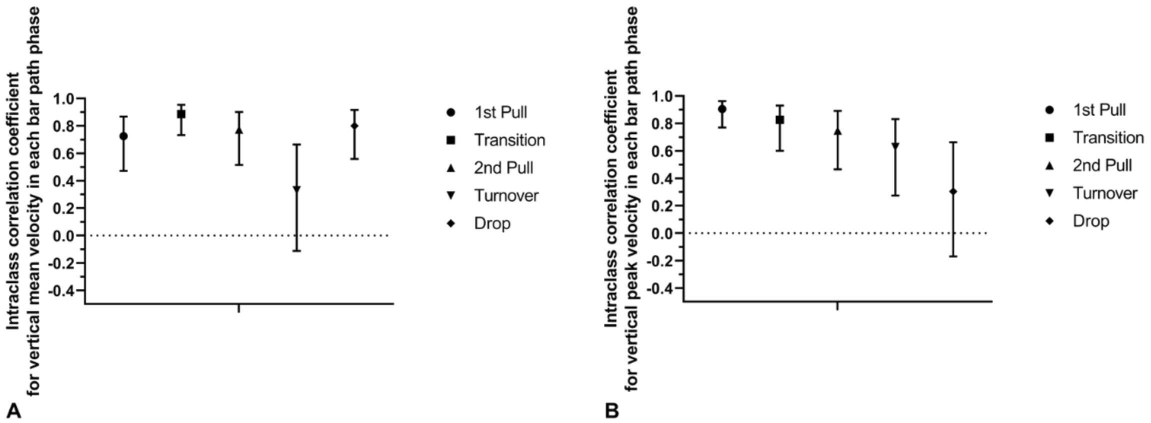

Figure 3. Intraclass correlation coefficient and its respective 95% confidence intervals between power snatch attempts. (A) Mean velocity in each phase of power snatch; (B) Peak velocity in each phase of power snatch

Table 5. Descriptive parameters from mean and peak acceleration during vertical displacement of the bar for each phase of power snatch attempts

Mean acceleration ($m \cdot s^{-2}$)										
Variable/ Phase	Attempt	Mean	95% CI	SD	Min	Max	Median	25-75 Percentile	MDC90	MDC95
1st Pull	first	1.96	1.62-2.30	0.69	0.29	3.17	2.04	1.70-2.45	0.59	0.71
	second	1.83	1.49-2.17	0.69	0.13	3.11	1.81	1.57-2.27		
	grouped	1.89	1.66-2.12	0.68	0.13	3.17	1.87	1.57-2.39		
Transition	first	3.23	2.67-3.79	1.13	1.37	5.08	3.55	2.12-4.13	1.36	1.62
	second	3.43	2.88-3.97	1.10	1.90	5.26	3.21	2.57-4.24		
	grouped	3.33	2.96-3.70	1.10	1.37	5.26	3.45	2.41-4.20		
2nd Pull	first	2.88	2.27-3.48	1.22	–0.49	4.32	3.04	2.10-3.70	1.91	2.28
	second	2.84	2.28-3.39	1.11	0.28	4.30	2.95	2.04-3.68		
	grouped	2.86	2.46-3.24	1.15	–0.49	4.32	3.03	2.07-3.69		
Turnover	first	–5.33	–5.93 - –4.73	1.21	–8.05	–3.46	–5.31	–5.86 - –4.64	1.60	1.91
	second	–5.50	–6.04 - –4.96	1.08	–7.80	–3.60	–5.54	–6.25 - –4.71		
	grouped	–5.41	–5.80 - –5.03	1.13	–8.05	–3.46	–5.36	–6.08 - –4.66		
Drop	first	–0.15	–0.33-0.03	0.36	–1.40	0.19	–0.02	–0.21-0.00	1.42	1.70
	second	0.04	–0.33-0.41	0.75	–1.65	1.38	0.00	–0.12-0.22		
	grouped	–0.05	–0.25-0.14	0.59	–1.65	1.38	0.00	–0.12-0.22		
peak acceleration ($m \cdot s^{-2}$)										
1st Pull	first	3.02	2.56-3.48	0.93	1.58	4.93	2.83	2.32-3.69	0.86	1.03
	second	2.97	2.39-3.54	1.16	1.06	5.52	2.90	2.35-3.32		
	grouped	2.99	2.64-3.34	1.03	1.06	5.52	2.85	2.33-3.53		
Transition	first	4.12	3.47-4.76	1.30	1.66	6.09	4.08	3.03-5.01	1.72	2.06
	second	4.35	3.69-5.01	1.33	2.28	7.06	4.35	3.25-5.19		
	grouped	4.23	3.80-4.67	1.30	1.66	7.06	4.20	3.16-5.17		

2nd Pull	first	4.98	4.33-5.62	1.31	2.41	6.78	4.90	3.78-6.28	1.30	1.55
	second	5.16	4.61-5.73	1.11	3.12	7.11	5.00	4.52-5.96		
	grouped	5.07	4.66-5.47	1.20	2.41	7.11	4.90	4.24-6.15		
Turnover	first	7.93	7.34-8.53	1.20	5.44	9.84	7.92	7.18-8.77	1.73	2.07
	second	8.42	7.89-8.96	1.08	6.03	10.10	8.68	7.79-9.06		
	grouped	8.18	7.79-8.57	1.15	5.44	10.10	8.36	7.42-9.04		
Drop	first	0.61	0.22-0.99	0.78	–0.55	2.68	0.36	0.00-1.00	1.63	1.95
	second	0.76	0.36-1.16	0.81	–1.03	2.17	0.76	0.00-1.29		
	grouped	0.68	0.42-0.95	0.79	–1.03	2.68	0.62	0.00-1.15		

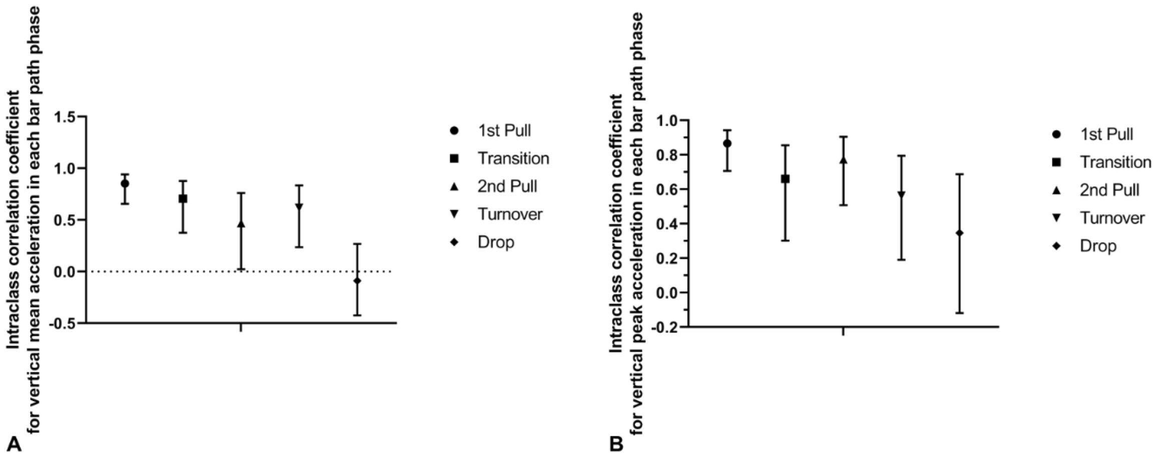

Figure 4. Intraclass correlation coefficient and its respective 95% confidence intervals between Power Snatch attempts. (A) Mean acceleration in each phase of power snatch; (B) Peak acceleration at each stage of the power snatch

the MDC from mean velocity, the values were relatively small for the transition and 2nd pull, while for peak velocity the relatively small MDC were observed for the 1st pull, transition, 2nd pull and turnover phases.

A greater mean acceleration was achieved at the transition phase, while a greater peak acceleration was achieved at the beginning of turnover phase. The reliability was excellent (ICC = 0.86 [0.66-0.95] for mean acceleration and 0.87 [0.69-0.95] for peak acceleration) only for 1st pull phase. Transition exhibited good reliability for both parameters (ICC = 0.72 [0.40-0.88] for mean acceleration and 0.67 [0.32-0.86] for peak acceleration), while the 2nd pull exhibited low reliability for mean acceleration (ICC = 0.48 [0.02-0.77]) and good reliability for peak acceleration (ICC= 0.78 [0.52--0.91]). Inversely, the turnover phase exhibited good reliability for mean acceleration (ICC = 0.63 [0.25--0.84]) and low reliability for peak acceleration (ICC = 0.58 [0.18-0.82]). Considering the MDC from mean and peak acceleration, the values were relatively greater for all phases.

Discussion

Identifying execution errors during sports gestures is essential to improve performance and reduce injury risk [3]. In this context it is necessary to know the "normal" movement pattern and the values within which the kinematic parameters of a given pattern are found, as well as the perspectives within which it is possible to modify these parameters. The present study collected kinematic data of the bar displacement during the performance of a power snatch by non-professional weightlifters, quantifying the values expected for each phase of this movement, which was inferred by the mean and 95% CI for each investigated variable. In addition, we inferred the reliability of these measures, as well as the perspective of MDC required for each parameter to achieve minimal clinical importance.

Our results showed the reliability ranging from low to excellent, depending on the studied variable (i.e., time of execution of each phase of the movement, horizontal and vertical bar displacement, velocity and acceleration of the bar) and the phase of the movement (i.e., 1st pull, transition, 2nd pull, turnover, drop). In general, the initial phases (i.e., 1st pull, transition, 2nd pull) of the power snatch movement showed better ICC values, while the worst values were identified in the final phases of the movement, especially the drop.

The 1st pull corresponds to the beginning of the Olympic weightlifter movements (i.e., clean and snatch) and is similar to the deadlift movement, which is commonly trained by OWT practitioners, whether competitors or not. In this way, this phase of the power snatch is highly trained and then it tends to be improved, leading to greater consistency, which may justify the higher ICC values and lower relative MDC values (i.e., considering the value of the MDC proportional to the mean of a variable). Additionally, the power snatch starts from a condition of inertia of the bar, while in the subsequent phases the bar is already in displacement and adjustments are inevitable, being directly dependent on the execution of the previous phase, which may contribute to worse ICC values and higher MDC values.

The duration of the movement as well as its each phase comprises the set of variables with the best reliability. In this context, it is noteworthy that the power snatch is characterized as explosive and, therefore, of short duration for its execution. Nevertheless, the average duration of the movement was 1.49 seconds (95% CI = = 1.43-1.55 seconds), time required to move the bar with the load referring to 60% of the PR at an average height of 1.47 meters (95% CI) = 1.43-1.51 meters), with an excellent ICC value (0.94 [0.84-0.98]).

It is important to emphasize that the height of the catch, used as a reference for the maximum height of the vertical bar displacement, showed excellent reproducibility, but the trunk and knee angles at the catching were on average 77.33º (95% CI = 75.00-79.65) for the trunk and 78.36º (95% CI = 76.05-80.67) for the knee, with ICC values between good (ICC = 0.77 [0.48-0.91] for the knee) and low (ICC = 0.59 [0.16-0.82] for the trunk). This fact indicates that these volunteers make effective adjustments in body position to fulfill the task objective with good reproducibility (i.e., moving the bar from the floor to an overhead position), thus suggesting that, despite their being non-professional weightlifters, the volunteers in this study exhibited a good body control to execute the movement. In this context, Ho et al. [11] suggested that investigations of the snatch technique should consider not only the variables related to bar displacement, but also those related to the subjects' body position.

From the biomechanical point-of-view vertical displacement is the largest, as a more efficient snatcher will be able to transition their body underneath the barbell with a shorter vertical pull [10, 13]. Therefore, adjustments in body position are an important aspect when considering technical quality in the snatch execution, as they are decisive in the bar path [11]. In this context, the reliability of horizontal bar displacement parameters DxT (ICC = 0.73 [0.41-0.89]), Dx2 (ICC = = 0.72 [0.40-0.88]) and DxV (ICC = 0.84 [0.62-0.94]) was good, with emphasis on reliability classified as excellent for the DxV parameter, measuring the horizontal bar displacement from the 2nd pull position to the most forward position [24].

Regarding movement duration, the transition phase is reported in several studies as important for a proper snatch technique [1, 4, 7, 8, 9, 11, 15]. In the present study we found that the duration of this phase is short, corresponding to approximately 0.12 seconds (95% CI = 0.10-0.30 seconds) or ~16.87% (95% CI = 14.79- -18.95%) of all the time required for power snatch execution and with an ICC = 0.64 (0.26-0.85). The knowledge of the mean duration and its 95% CI can help to identify less effective patterns in this phase (i.e., the transition between the 1st and 2nd pull), which is reported as one of the main determinants in the success of a snatch [14], as will be discussed in more detail.

The velocity and acceleration parameters (mean and peak) are among the variables of greatest interest in studies investigating kinematic characteristics of snatch. In fact, these variables are decisive for power output, which in turn is essential for the successful task execution. In the present study we identified the highest mean and peak velocity values in the 2nd pull, while the highest mean and peak acceleration values were recorded in the transition and turnover phases, respectively. The observation of higher mean and peak velocity values is expected in the 2nd pull, which corresponds to a phase, which objective is to maximize bar velocity through a coordinated and explosive triple extension (i.e., hip, knee and plantar flexion), projecting the bar to an overhead position [4].

Identifying the highest mean acceleration values in the transition phase between the 1st and 2nd pull shows that the slowdown in the transition phase between the 1st and 2nd pull is one of the main determinants for success/ failure of snatch attempts at maximum loads, as stated

by Kipp and Harris [14]. Deceleration in this phase leads to lower mean acceleration values and will imply greater needs for acceleration in the subsequent phase (i.e., 2nd pull). It is important to note that in the present study submaximal loads were used, unlike the study of Kipp and Harris [14], who investigated maximum loads and squat snatch movements in competitive athletes.
Notwithstanding, maintaining the velocity of vertical bar displacement in the transition phase should be considered important also at submaximal loads, since decelerations will also demand greater velocity gains in the 2nd pull. Thus, a better maintenance of velocity in the transition phase will reduce the need to develop acceleration in the 2nd pull phase, making the movement more efficient. This can be advantageous when the objective is to perform multiple repetitions of the power snatch in the same set or within the same training session, as commonly used in many workouts of MMT programs.
It is worth mentioning that the ICC measurements indicated excellent reliability for mean and peak velocity (0.74 to 0.91) for the 1st pull, transition and 2nd pull. The turnover and drop phases presented lower reliability for mean and peak velocity, likely because they are predominantly phases of deceleration. In contrast, ICC values for peak acceleration were consistently high between the early phases (1st pull, transition and 2nd pull phases – ICC range = 0.67-0.87), while the later phases (transition and turnover) presented high ICC values for mean acceleration (ICC range = 0.63-0.72).

Conclusions
Summarizing the findings of the present study, recreational weightlifters with at least 1 year of training exhibited a good movement pattern, with good reliability at crucial phases of power snatch. The presented data, with a comprehensive description of normative data for power snatch obtained from recreational weightlifters, could help coaches to evaluate a range of people who use power snatches as a conditioning tool for other sports.
It is important to mention that the present study chose to analyze the power snatch instead of the squat snatch (i.e., full snatch, where the knee angle is less than 90°), since power snatch, typically performed with a lighter weight, as in this study (i.e., 60% of RM), allows greater barbell velocity, leading to greater barbell height, as well as the high squat catch position [22]. This higher catch position does not require the athlete to go into a full overhead squat position, which can be difficult to achieve for recreational weightlifters. Additionally, the power snatch catch position is similar to an athletic ready position (e.g., when preparing to or recovering from a jump), providing greater familiarity with the lift [22]. These aspects provide applicability of our results applicability in daily practice for a large number of weightlifting enthusiasts.

Conflict of Interests
The authors declare no conflict of interest.

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