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RESEARCH ARTICLE

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Postural control during the back squat at different load intensities in powerlifters and weightlifters

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ABSTRACT

Background: The movement of the barbell has been detected as success factor for the snatch and the clean and jerk events. As the barbell's movement has been shown to be related to the athlete's body movement, we hypothesized that the latter could be a success factor also for the back squat (BS) event. Hence, this study aimed to investigate postural control during the execution of the BS at different load intensities in powerlifters and weightlifters.
Methods: Seventeen powerlifters and weightlifters were enrolled and the one-repetition maximum (1-RM) of the BS of each participant was measured. Afterwards, the assessment of postural control during the execution of the BS at different load intensities (i.e. 60%, 70%, 80%, 90%, 100%) of the 1-RM of each participant was carried out through a posturographic platform to measure the displacement of the centre of pressure (CoP). The following parameters were considered: sway path length (SPL), sway ellipse surface (SES), length/surface (LFS ratio), sway mean speed (SMS), CoP coordinates along X and Y planes.
Results: We found a significant increase in SPL and LFS ratio, and a significant decrease in SMS as the load intensity increased. In detail, we detected a significant difference in: (a) SPL between the BS at 60% and 80%, 60% and 90%, 60% and 100%; between the BS at 70% and 90%, 70% and 100%; between the BS at 80% and 100%; and between the BS at 90% and 100%; (b) SMS between the BS at 60% and 80%, 60% and 90%; (c) LFS ratio between the BS at 60% and 90%, 60% and 100%.
Conclusions: These results suggest that powerlifters and weightlifters adopt different postural control strategies depending on the load intensity when performing the BS. Our findings showed that higher effort could affect postural control during the BS. Thus, postural control could be considered a success factor for the BS.

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Biomechanics; back squat; postural control; powerlifting; weightlifting

Introduction

Among strength and power sports, powerlifting and weightlifting have a widespread popularity representing the most commonly practiced around the world [1, 2]. The latter refers to lift the maximum weight in specific exercises depending on the sport and respecting certain judging criteria [1, 2].

In powerlifting, the judge takes into consideration the maximum weight lifted regardless of the execution time of the exercise, while in weightlifting the execution velocity of the exercise is also considered [2]. This aspect reflects the different nature of strength performance between these sports by emphasizing the ability to produce maximum muscle force in relation to time, i.e. maximum strength or power [2].

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Specifically, in weightlifting competitions athletes are required to lift the maximum weight possible in one repetition in the events of the snatch and the clean and jerk [3]. The athletes have three attempts, and the maximum load is recorded as the athlete's final score of the competition. However, the athlete is eliminated from the competition in case of failure in all the three attempts [4]. In powerlifting competitions, athletes are required to lift the maximum load in a single repetition with three attempts available in the events of the back squat, bench press and deadlift [5]. The best one-repetition maximum (1-RM) load of each attempt successfully lifted for each event is summed giving a total score of the competition [6].

In both powerlifting and weightlifting training programmes, the back squat exercise is widely used. As a matter of fact, while in powerlifting this represents a competitive exercise, weightlifting athletes include the back squat as complementary exercise in training program, as it has a pattern movement similar to competitive exercise [3]. In the back squat, the barbell is positioned behind the shoulders and across the trapezius muscle. It can be differentiated into: (1) high-bar back squat (HBBS) in which the barbell is positioned across the top of the trapezius muscle, immediately below the spinous process of the C7 vertebra; (2) low-bar back squat (LBBS) in which the barbell is positioned across the lower trapezius muscle, immediately above the posterior deltoid and along the spine of the scapula. The HBBS is commonly used by weightlifting athletes while the LBBS by powerlifting athletes [7]. Regardless of two different variations of the back squat, several studies analysed different aspects of the back squat such as kinematics, kinetics and electromyographic activities of the recruited muscles during the execution of the exercise in both powerlifting and weightlifting athletes, regardless of gender, weight and age categories [7–13]. A seminal study reported that the execution of the back squat with high weights, approaching the 1-RM, is a measure of different lower body characteristics such as strength, power, balance and coordination [14]. This is related to the fact that the back squat is a multijoint exercise involving large muscle mass and requiring a proper technique that led to fitness improvements in terms of the above-mentioned characteristics [14, 15]. Indeed, the back squat mainly involving hips, knees, ankles joints and lower limbs, back and core muscles [16].

Much research has investigated the factors that can affect the successful attempt of the competitions' events. For example, the trajectory, velocity and displacement of the barbell were detected as success factors in both the weightlifting events of the snatch and the clean and jerk [17–20]. Furthermore, the latter parameters can also be affected by different load intensities of the 1-RM [21]. Moreover, it has been shown that the barbell movement is related to the athlete's body movement, i.e. to the athlete's centre of gravity (CoG) [21, 22]. Based on this knowledge, we suppose this could also be transposed into the other events of the competitions of both sports which, however, have been little investigated in terms of success factors. In detail, as the movement of the barbell is related to the body movement of the athlete's, we hypothesized that athlete's body movement could affect the successful attempt of the back squat. As a matter of fact, postural control can affect performance in several sports [23–25]. Thus, the aim of this study was to investigate postural control during the execution of the back squat at different load intensities in powerlifters and weightlifters.

Materials and methods

Study design

In this cross-sectional study, we analysed postural control, through a posturographic platform, during the execution of the back squat at different load intensities (i.e. 60%, 70%, 80%, 90%, 100%) of the 1-RM in powerlifters and weightlifters.

The study, in accordance with the recommendations of the Declaration of Helsinki for the involvement of people in research, was conducted with the approval of the Bioethics Committee of the University of Palermo (n. 99/2022).

Participants

Participants were powerlifters and weightlifters recruited from a sports club in Palermo, Italy. The research was first presented to the president of the sports club and, after agreement of availability to participate, it was presented to the athletes inviting them to participate on a voluntary basis by providing written informed consent.

The following inclusion criteria had to be met: (1) at least 3 years of powerlifting/weightlifting practice; (2) at least 3 training sessions/week of frequency; (3) at least 1.5 of relative strength. The following exclusion criteria were established: (1) minor athletes; (2) serious musculoskeletal injuries within the previous 6 months; (3) athletes who practiced specific training sessions for balance.

Seventeen powerlifters and weightlifters ($m = 12$, $f = 5$; age: 26.86 ± 8.93 years; weight: 73.29 ± 13.56 kg;

height: 170.88 ± 8.15 cm) met the abovementioned criteria and were recruited for the study.

Procedure

The procedure involved two phases one week apart. In the first phase, the 1-RM of the back squat of each participant was measured. In the second phase, the assessment of postural control during the execution of the back squat at different load intensities (i.e. 60%, 70%, 80%, 90%, 100%) of the 1-RM of each participant was carried out.

To standardize the procedure all participants were asked to perform the LBBS for both phases. It appears that LBBS may allow to lift higher loads [7].

All measurements were carried out in the gym of the sports club and in the time slot from 2.00 pm to 4.00 pm.

First phase: 1-RM measurement of the back squat

The predicted 1-RM was estimated according to the maximum repetitions test in which each participant had to lift a weight that fell between 5 and 10 repetitions [26].

After an adequate self-managed warm-up, each participant was asked the load with which was able to perform 10-12 repetitions. From this weight, to which 20% was added, the first series of tests began. If the number of repetitions did not fall within those established (i.e. between 5 and 10), a further 20% load was added and, after a 5-minute rest, the second series of tests was performed. Hence, the predicted 1-RM was computed through the Brzycki formula: Predicted 1-RM = weight lifted/[1.0278 - (0.0278 * number of repetitions performed)] [27].

Second phase: postural control measurement of the back squat

For this phase, a warm-up was planned before data collection. At this stage, no indication was given, and all participants carried out their usual warm-up. All participants belonged to the same club and were trained by the same coach who was present throughout the procedure. Their usual warm-up lasted 15 min and included joint mobility exercises, dynamic stretching exercises and weight-free back squats.

Then, for data collection, each participant performed five trials in each of which performed one repetition of the back squat for each load intensity (i.e. 60%, 70%, 80%, 90%, 100%) of the 1-RM. All trials were performed in order of increasing load intensity and a rest period of at least 3 min between trials was scheduled.

All trials were carried out with participants performing the back squat on a posturographic platform (freeMed®; Sensor Medica®; Guidonia Montecelio, Rome, Italy), and the related software (freeStep®; Sensor Medica®; Guidonia Montecelio, Rome, Italy), using a sampling frequency of 50 Hz. This allows to measure the displacement of the centre of pressure (CoP) during the execution of the back squat at each load intensity. The following parameters of the CoP were considered: sway path length (SPL, mm), sway ellipse surface (SES, mm^2), sway path length/sway ellipse surface (LFS ratio, i.e. length as function of surface), sway mean speed (SMS, mm/s), CoP coordinates along X and Y planes.

The execution of the back squat was as follows. From the starting position of the back squat, with the hips and knees fully extended and the barbell positioned across the shoulders, each participant was required to flex the hips and knees until the thighs were parallel to the floor (i.e. descent phase of the back squat) and, subsequently, to extend the hips and knees until reaching again the starting position (i.e. ascent phase of the back squat) [6, 16].

All trials were performed using Olympic barbell and weight plates. Participants were not allowed to use any type of equipment in order to control for any potential effect of these on performance as it is not yet clear whether equipment such as belts or straps can affect performance [28, 29]. Participants performed all trials wearing their own technical shoes.

Statistical analysis

The Shapiro–Wilk test was used to evaluate data distribution. A descriptive analysis reporting means and standard deviations of the data was performed. The one-way repeated measures ANOVA was carried out to assess any differences for each parameter considered (i.e. SPL, SES, LFS ratio, SMS and CoP coordinates along X and Y planes) among the trials at different load intensities (i.e. 60%, 70%, 80%, 90%, 100%) of the 1-RM. The Tukey's post hoc multiple comparisons test was performed to analyse the significant difference between the trials. The partial eta-squared was used to assess the effect size. The *p*-value was set significant at < 0.05.

Data were analysed using Jamovi software package (version 2.3.28) [30]. Graphs were created using GraphPad Prism (version 8.0.2; GraphPad Software, Inc.; Boston, Massachusetts, USA).

Results

Table 1 shows the 1-RM values of all participants.

All participants were able to complete all the five trials at different load intensities (i.e. 60%, 70%, 80%, 90%, 100%) of the 1-RM. As the load intensity increased, the one-way repeated measures ANOVA showed a significant increase in SPL ($F_{(4,64)}$=33.9; $p < 0.001$; ηp^2=0.679), a significant increase in LFS ratio ($F_{(4,64)}$=5.73; $p < 0.001$; ηp^2=0.264), and a significant decrease in SMS ($F_{(4,64)}$=5.88; $p < 0.001$; ηp^2=0.269).

As showed in Figure 1, the Tukey's post hoc multiple comparisons test detected a significant difference in SPL between the back squat at 60% and 80% ($p < 0.01$), 60% and 90% ($p < 0.001$), 60% and 100% ($p < 0.001$); between the back squat at 70% and 90% ($p = 0.002$), 70% and 100% ($p < 0.001$); between the back squat at 80% and 100% ($p = 0.001$); and between the back squat at 90% and 100% ($p < 0.001$). As showed in Figure 2, the Tukey's post hoc multiple comparisons test showed a significant difference in SMS between the back squat at 60% and 80% ($p = 0.012$), 60% and 90% ($p = 0.002$). As showed in Figure 3, the Tukey's post hoc multiple comparisons test showed a significant difference in LFS ratio between the back squat at 60% and 90% ($p < 0.001$), 60% and 100% ($p = 0.005$).

No significant differences ($p > 0.05$) were detected for the other CoP parameters considered (i.e. SES and CoP coordinates along X and Y planes).

Figure 4 shows the CoP displacement during the back squat across the different load intensities of one participant.

Discussion

The aim of this study was to investigate postural control during the execution of the back squat at different load intensities in powerlifters and weightlifters.

Our results showed an increase in CoP parameters such as SPL and SMS as the load intensity increased.

Previous studies have investigated the factors for the successful attempt of the competitions' events and, in particular, the trajectory, velocity and displacement of the barbell were detected as success factors for the snatch and the clean and jerk [21, 22]. However, no research groups have explored the success factors of the back squat although the movement of the barbell could also affect the attempt of this event. The existing literature have demonstrated the relationship between the movement of the barbell and the CoG movement of the athlete [21, 22]. Regarding this topic, it is widely known that postural control can be assessed by measuring related parameters such as the trajectory, velocity and displacement of the CoG or of the CoP and this knowledge provides a rationale for the appropriate approach used in the present study [31, 32]. Indeed, the role of postural control in powerlifters and weightlifters has been established in previous studies [33–35] and it seems that postural control could influence the maximum weight lifted [36]. As a matter of fact, Kollmitzer et al. showed that any voluntary movement of the body leads to internal perturbations of the balance which augment as the load to be lifted increases [37]. This concept supports the hypothesis we formulated for the present study which is confirmed by our results. In fact, the CoP displacement represents an indicator of the overall neuromuscular

Table 1. Participants' 1-RM values.

ID	Sex	Sport	60% of the 1-RM (kg)	70% of the 1-RM (kg)	80% of the 1-RM (kg)	90% of the 1-RM (kg)	1-RM (kg)
1	F	WL	72	84	96	108	120
2	M	PL	120	140	160	180	200
3	F	PL	42	49	56	63	70
4	M	PL	72	84	96	108	120
5	F	PL	46	53	61	68	76
6	M	PL	60	70	80	90	100
7	M	PL	69	80	92	103	115
8	F	WL	63	73	84	94	105
9	M	PL	102	120	137	154	171
10	M	PL	96	112	128	144	160
11	M	PL	60	70	80	90	100
12	M	PL	66	77	88	99	110
13	M	PL	120	140	160	180	200
14	M	PL	84	98	112	126	140
15	F	WL	42	49	56	63	70
16	M	PL	90	105	120	135	150
17	M	PL	87	101	116	130	145

WL, weightlifting; PL, powerlifting.

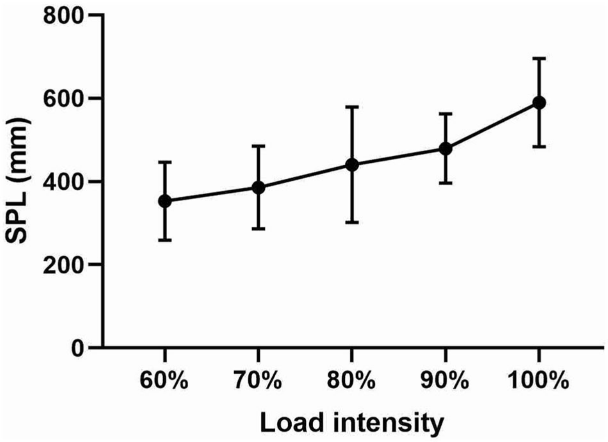

Figure 1. Differences in SPL parameter of the CoP during the back squat at different load intensities. SPL, sway path length.

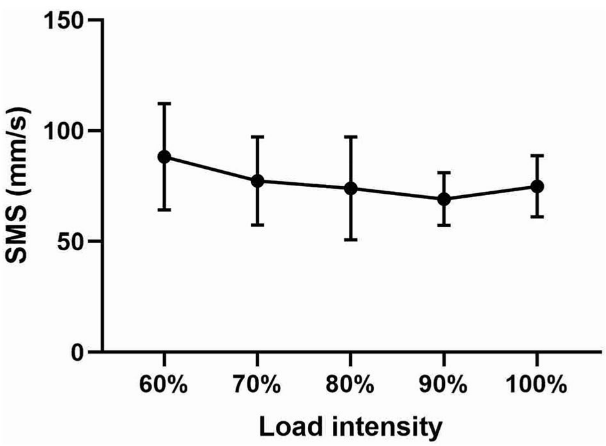

Figure 2. Differences in SMS parameter of the CoP during the back squat at different load intensities. SMS, sway mean speed.

response for maintaining postural control during a body movement, such as the back squat, and it is associated with the CoG movement [38]. The CoP displacement and the amplitude of the related parameters such as the SMS are outcomes of motor control [39]. In this way, the body should be maintained as stable as possible during the execution of a sport-specific task by avoiding compensatory movements and making anticipatory postural adjustments to counteract the perturbation [37, 39, 40]. These involuntary and automatic movements are different depending on the specificity of the task and ensure the accurate and harmonious execution of the movement [37]. In detail, changes in the strategies or in the activation levels of the recruited muscles can be postural adjustments during lifting [37].

Indeed, changes in exercise technique affect muscle pattern activity during the back squat [41]. As already demonstrated in previous studies, the muscle activation of the lower limbs increased as the load increased

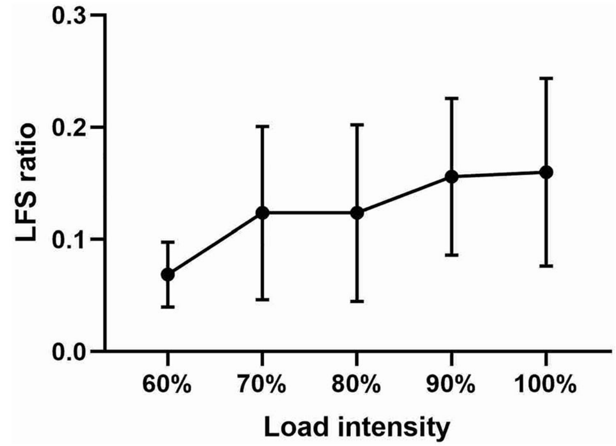

Figure 3. Differences in LFS ratio parameter of the CoP during the back squat at different load intensities. LFS ratio, sway path length as a function of the sway ellipse surface.

during the execution of the squat [42]. For example, Paoli et al. found an increase in lower limbs muscle activation during the squat performed at load intensities of 0%, 30% and 70% of the 1-RM with significant differences only between the lowest and highest load [41]. Different studies have examined the relationship between motor units synchronization and the physiological muscle tremor, which represents the fluctuations in muscle force and, it appear that muscle tremor increases at strong muscular contractions (i.e. tremor increases at greater level of motor units synchronization) and this is emphasized during submaximal contractions [43–45]. In the present study we found a significant increase in postural sway (CoP displacement) as the load intensity increased and we suppose that, since at higher load intensities the muscle tremor increased, this determined a greater displacement of the CoG which was reflected in a larger amplitude of the displacement of the CoP. Indeed, to manage postural control during dynamic movements, the development of appropriate and coordinated muscular efforts is required to maintain the vertical projection of the CoG within the base of support [46].

This is also related to the results that we found in the LFS ratio parameter (i.e. the sway path length as a function of the sway ellipse surface of the COP) which represents an index of energy expenditure [47, 48]. Indeed, we detected significant differences from 60% to 90% and 100% highlighting that with high muscular efforts there is also a high effort in postural control.

It should be noted that the choice of the present research to recruit high-level powerlifting and weightlifting athletes with a suitable sport-specific background (as they participated in regional or national competitions) is supported by previous studies. In fact, Munzert et al. investigated postural control in dancers

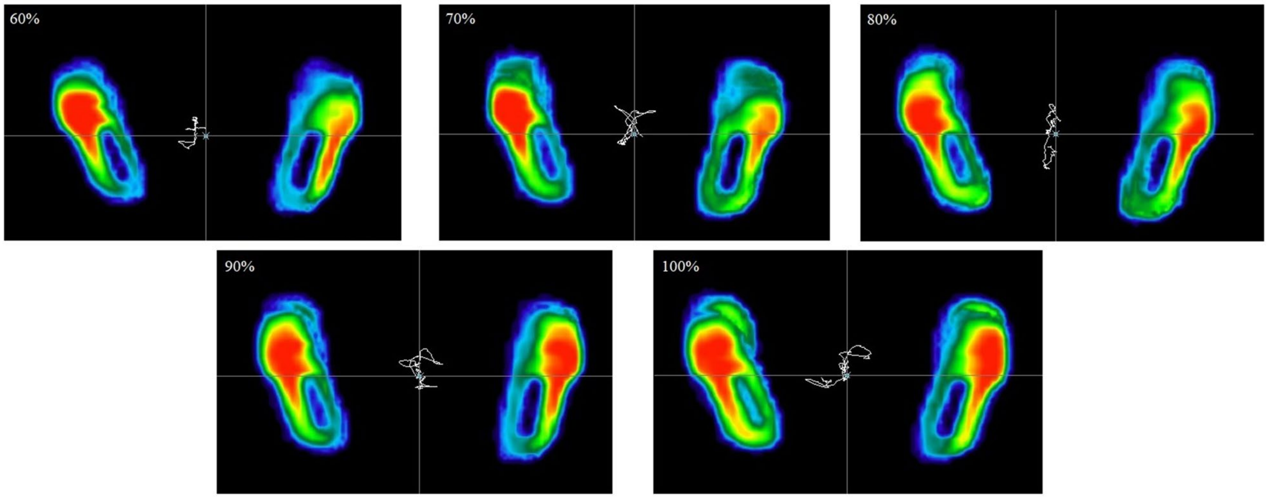

Figure 4. CoP Displacement during the back squat across the back squat at different load intensities of one participant.

during different balance tasks, i.e. six static activities of daily living and five dynamic dance-specific activities, performed on a force plate to study the CoP displacement by comparing expert and intermediate dancers [39]. Results showed better levels in the SES parameter for the dance-specific activities in expert compared to intermediate dancers. These findings indicate that a sport-specific task is performed better by experts and emphasize the specificity of postural performance in sport [38, 39].

Conclusions

Based on our results, powerlifters and weightlifters appear to adopt different postural control strategies depending on the load intensity when performing the back squat. Our findings showed that higher effort could affect postural control during the back squat and therefore that postural control could be considered a success factor for the back squat.

Strengths and limitations

The main strength of the study is its originality. In fact, to the best of our knowledge, no research has previously investigated postural control during the execution of the back squat at different load intensities. Further strengths of the study are the homogeneity of the sample, as well as having controlled some variables such as the absence of any type of equipment which could have affected the performance.

Among the limitations of the study, we report the 1-RM measurement of the back squat which was estimated and not measured *via* direct test.

Practical implications

These findings may be of interest to coaches of powerlifting and weightlifting athletes as it highlights the importance of postural control when performing the back squat. Therefore, it may be important to include body balance exercises in training program of these athletes.

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Authors contributions

V.G. conceived and designed the study; F.F., N.S. and D.S.S.V. helped to run the study; V.G. and A.Pat. conducted the statistical analyses; V.G., E.T. and A.Pao. interpreted the results; A.Pao. provided critical feedback; V.G. drafted the manuscript; A.Pat. edited the manuscript; M.T. and P.D. advised on the technical aspects; A.Pal., G.M. and A.B. supervised the study. All authors approved the final version of the paper and agreed to be accountable for all aspects of the work.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

The data that support the findings of this study are available from the corresponding author, A.Pat., upon reasonable request.

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