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Original research papers

MODELLING FRONT AND BACK SQUAT RECORD SCORES IN LONG-TERM TRAINING OF YOUNG WEIGHTLIFTERS

PAULINA SZYSZKA[1], WERONIKA ZIELIŃSKA-STUBIŃSKA[2], AGNIESZKA CHWALUK[3]

Józef Piłsudski University of Physical Education in Warsaw, Faculty of Physical Education and Health in Biała Podlaska,
[1]Department of Sport and Training Sciences, [3]Department of Biomechanics and Anatomy, Poland
[2]Scientific School of the University of Physical Education in Warsaw - SN No. 5

Mailing address: Paulina Szyszka, Józef Piłsudski University of Physical Education in Warsaw, Faculty of Physical Education and Health, 2 Akademicka Street, 21-500 Biała Podlaska, tel.: +48 (83) 3428700, e-mail: paulina.szyszka@awf.edu.pl

Abstract

Introduction. Front and back squats are multi-joint exercises used in sports to develop strength, power and muscle mass. Due to their movement structure and involvement of the main muscle groups, they are training measures that are used in strength training in various sports. A long-term training process leading to sports mastery requires the correct selection of loads as well as objective control of the training effects to date, both short-term and long-term. The aim of this study was to create a statistical model and to determine with it the character of the changes in the record scores in the front and back squat of young weightlifters over a two-year training cycle. ***Material and Methods.*** The study included 17 young athletes training in competitive weightlifting. Recorded scores in the front squat and back squat were measured seven times (every three months over a two-year training cycle). The progression method was used to determine the maximum load, and the repetition with the highest load (1RM) was used in the calculations. ***Results.*** The subjects performed better in the back squat, but the difference between the results for both squats was approximately constant over the two-year training cycle. The time courses of both squats were similar over the analysed period. Systematic increases in maximum results were observed. The first statistically non-significant differences between the mean record values in successive measurements were found between the sixth and seventh measurements for both squats. ***Conclusions.*** Determining the relationship between front and back squat record scores can contribute to the optimisation of training loads in sports using strength training. Obtaining an analytical form of the course of record scores over time for both squats helps to assess the skill level of athletes and predict their performance in the next training macro-cycle.

Key words: squat, training loads, record progression, modelling

Introduction

The squat is one of the simple multi-joint exercises and its characteristic feature is the closed kinematic chain of the upper and lower extremities. As a training tool, it is used to develop strength, power and muscle mass [1, 2]. Squats also enhance human movements in many sports, e.g. jumping and sprint running [3, 4, 5, 6], and as a strength exercise they are used in sports such cross-country skiing [7], long-distance running [8], cycling [9] and in endurance sports [10]. Many authors point to improvements in overall strength and economy of movement as influenced by the use of squats in football, handball or rugby training programmes [11, 12, 13]. Pozzo et al. [14] point out the similarity of the squat to movements specific to selected cyclic sports (alpine skiing, rowing) and acyclic sports such as jumping or judo [14].

Squats can be performed with a variety of instruments, among which the barbell is the most frequently used. Its position relative to the body determines the three basic types of squat. The most commonly used one is the high bar back squat, in which the barbell is held high on the back in the upper quadriceps area. The second type of this squat is the low bar back squat, in which the barbell rests in the lower region of the quadriceps muscles [15]. When performing the low bar back squat, the athlete is able to lift a much heavier load [3, 15, 16 ,17], while the high bar back squat is considered to be safer in terms of intervertebral spinal loads [15, 17]. The third type of squat is the front squat with the barbell held on the chest. The front squat is considered a safe exercise often used in rehabilitation or by beginners [16, 18]. Studies of both types of squats indicate greater trunk verticalisation in the front squat, which translates into lower shear forces in the lumbar spine [16, 18]. On the other hand, Spitz [19] did not confirm a significant difference in barbell velocities, nor Davis [20] a significant difference in energy expenditure of the body during front and back squat performance. It has also been shown that muscle activation levels are at similar levels in both squats [21]. Weightlifting athletes use the high bar back squat and the front squat. This is due to the similarity to the phase of the squat and standing up in the snatch and to the phase of the squat and standing up from the clean and half squat during the jerk [22, 23, 24, 25].

Long-term analysis of record scores in selected exercises is essential, both from the sporting perspective as well as the adaptive changes occurring in young athletes under the influence of strength training [26, 27]. In strength training itself, the correct selection and distribution of loads to increase the athletes' exercise capacity is of primary importance [28]. Front and back squats are among the leading exercises used in this context [22].

With the above in mind, the main aim of this study was to create a statistical model and identify with it the time courses of

record scores in the front squat and back squat in young weightlifters over a two-year training cycle.

Material and Methods

The subjects and research methodology were described in detail in our previous work [26]. Briefly, 17 young weightlifters with at least one year of training experience participated in the study. The athletes were 18.6 ± 2.6 years old and had a body weight of 70.8 ± 18.2 kg at the start of the measurements. They were given information about the intended measurements and the possible risks and benefits of participating in the study. They were also examined and admitted to the study by a doctor. The subjects and their parents signed written informed consent forms. The study was conducted in accordance with the ethical standards of the Declaration of Helsinki and was approved by the Research Ethics Committee of the University of Physical Education in Warsaw. Measurements were carried out in a two-year training cycle. Record scores in both squats were measured in random order every three months during the first week of the month. All trials were conducted at the beginning of the training unit. They were preceded by a warm-up with a load of no more than 90 per cent of the weightlifter's personal record score in the respective squat. A progression method with an increase in load between successive repetitions of 3 or 5 kg was used to determine the maximum load (1 RM). The percentage of both squats in the training programme during the analysed period was about 10%. Depending on the training period, athletes used loads from 70-90% RM in at least 6 series in different repetitions.

Modelling and statistical analysis

The modelling of the empirical data was based on a regression approach using a hierarchical model [29, 30]. Repeated measurements were placed at the first level (Level-1) and nested within individual subjects (Level-2) (Fig. 1). Based on a visual assessment of the measurement data, the analytical relationship between the repeated measurements was defined as a second-degree polynomial. This modelling approach is referred to as the individual growth curve approach.

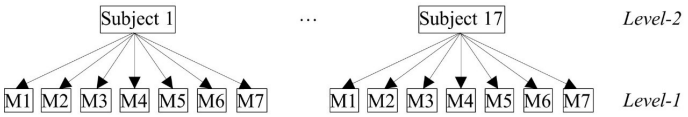


Figure 1. A hierarchical model with repeated measures.

The preparation of the long format measurement data, the derivation of the regression equations, and the inclusion of the time-independent co-variable (TIC) in these equations were described in detail in our previous work [26, 31]. However, to facilitate the interpretation of the results obtained, it should be mentioned that the time of the first measurement session was coded as *time* = 0, the interval between measurements was 0.25 (one quarter), the TIC was defined as the grand-mean cantered initial age of a participant, and the final, most expanded regression equation took the form:

$$FS_{ij} = \gamma_{00} + \gamma_{01}TIC_j + \gamma_{10}time_{ij} + \gamma_{11}time_{ij}TIC_j + \gamma_{20}time_{ij}^2 + \gamma_{21}time_{ij}^2TIC_j + \cdots$$
$$+u_{oj} + u_{1j}time_{ij} + u_{2j}time_{ij}^2 + r_{ij} \qquad (1)$$

where *FS* stands for front squat, lower subscripts i (1 ÷ 7) denote measurement sessions and j (1 ÷ 17) subjects, *gammas* are regression coefficients, u_{0j}, u_{1j}, and u_{2j} represent random deviations from the intercept, initial slope and quadratic term for the subject j, and r_{ij} stands for within-subject residual error.

The computations were carried out in the R environment. The *lme* function from the *nlme* package [31] was applied for hierarchical models and the *gls* function was used when testing statistically significant differences between repeated measurements. The latter was called with the argument *corAR1()* due to the presence of correlations between successive measurements.

In the regression approach, one generally builds several models and chooses as the final model the one that best fits the measurement data. We built 3 models for each type of squat, i.e. random intercept models (FS_0, BS_0), unconditional growth curve models (FS_1, BS_1) and models with TIC (FS_2, BS_2). These were defined as follows:

FS_0 <- *lme*(*fs* ~ 1, *random* = ~ 1|*subject*, *data* = *squat*, *method* = "REML") (2)

FS_1 <- *lme*(*fs* ~ *time* + *I*(*time*^{2}), *random* = ~ *time* + *I*(*time*^{2})|*subject*, ...) (3)

FS_2 <- *lme*(*fs* ~ (*time* + I(*time*^{2})) * *iac*, *random* = ~ *time* + I(*time*^{2})|*subject*, ...) (4)

where *fs* denotes a reference to a column of record scores for squat in the data file, *REML* denotes the restricted maximum likelihood method, *iac* the grand mean-centered initial age of the subject, and the asterisk operator additionally introduces cross-level interactions *time*iac* and *time2*iac* into the model. The use of the identity function *I*() also needs explanation. It enforces an arithmetic operation in parentheses, which ensures linearity of the model with respect to the variables.

Statistical significance in all analyses was set at $p < 0.05$.

Results

The modelling results for the front squat are shown in table 1. The values of all regression coefficients, except γ_{01}, were found to be significantly different from zero. This means that the intercept, initial slope and curvature of the record scores trajectories in this exercise differed between subjects. The non-significant coefficient γ_{01} indicates no relationship between intercept and grand-mean centred initial age (*iac*). A value of *-2LL* indicates that the random intercept model FS_0 showed the worst fitting to the measurement data. There was also no statistically significant difference between the FS_1 and FS_2 models. Indeed, the value of the chi-squared statistic for *-LL* = 3.52 (the difference in between models) was $\chi^2 = 7.04$ at $p < 0.071$.

The modelling results for the back squat are shown in table 2. As in the previous case, the values of all regression coefficients, except coefficient γ_{01}, were found to be significantly different from zero. This means that the intercept, initial slope and curvature of the time courses of record scores in the back squat differed between subjects. The random coefficients model BS_0 showed again the lowest fitting to the measurement data, while the difference between models BS_1 and BS_2 was found to be statistically insignificant. The chi-squared statistic for *-LL* = 3.48 took the value of $\chi^2 = 6.96$ at $p < 0.073$.

The aforementioned variation in the time courses of record performance in the front squat FS1 of individual subjects is illustrated in figure 2. The thick line shows the average time course over the individual time courses. The graph for the back squat (BS_1), not published in this paper, is of a similar pattern.

Table 1. Estimation of forward squat models' parameters

Parameter	FS_0	FS_1	FS_2
	Coefficient (SE)		
Fixed effects			
Intercept (γ_{00})	131.40*** (5.74)	117.47*** (6.35)	117.47*** (6.32)
Time (γ_{10})		21.67*** (2.86)	21.66*** (2.27)
Time^2 (γ_{20})		−2.85* (1.66)	−2.84* (1.38)
Initial_age (γ_{01})			1.87 (2.50)
Time*Initial_age (γ_{11})			-2.85* (1.38)
Time2*Initial_age (γ_{21})			1.52* (0.54)
	Variance (SD)		
Random effects			
Level-1 residual	106.32 (10.31)	4.35 (2.08)	4.35 (2.08)
Level-2 residuals			
Intercept	539.93 (23.24)	664.08 (25.77)	641.45 (25.33)
Slope		32.35 (5.69)	51.22 (7.16)
Quadratic term		4.66 (2.16)	15.50 (4.18)
−2LL	954.18	691.86	682.88

* – p < 0.05, *** – p < 0.001, LL – log likelihood.

Table 2. Estimation of back squat models' parameters

Parameter	BS_0	BS_1	BS_2
	Coefficient (SE)		
Fixed effects			
Intercept (γ_{00})	146.87*** (6.21)	132.09*** (6.88)	132.09*** (6.77)
Time (γ_{10})		24.96*** (3.59)	24.95*** (2.78)
Time^2 (γ_{20})		−4.84* (1.82)	−4.84* (2.67)
Initial_age (γ_{01})			2.68 (3.96)
Time*Initial_age (γ_{11})			-3.73*** (1.10)
Time2*Initial_age (γ_{21})			1.77* (0.58)
	Variance (SD)		
Random effects			
Level-1 residual	114.72 (10.71)	5.68 (2.38)	5.68 (2.38)
Level-2 residuals			
Intercept	634.12 (25.18)	780.88 (27.94)	735.04 (27.11)
Slope		171.45 (13.09)	82.76 (9.09)
Quadratic term		37.32 (6.11)	17.28 (4.16)
−2LL	964.64	718.90	708.88

* – p < 0.05, *** – p < 0.001, LL – log likelihood.

The mean time courses for the unconditional FS_1 and BS_1 models are depicted in figure 3. It is evident that there is a consistent difference between the record scores during the two training macrocycles. The first statistically non-significant differences between the mean values of the record scores in successive measurement sessions were only found between the sixth and seventh measurements for both squats (empty dots in Fig. 3). Due to the scale of figure 3, it is not obvious that the BS_1 trajectory has a greater initial slope (24.96 kg/quarter versus 21.67 kg/quarter) and greater curvature (-4.84 kg/quarter^2 versus -2.85 kg/quarter^2) compared to the FS_1 trajectory.

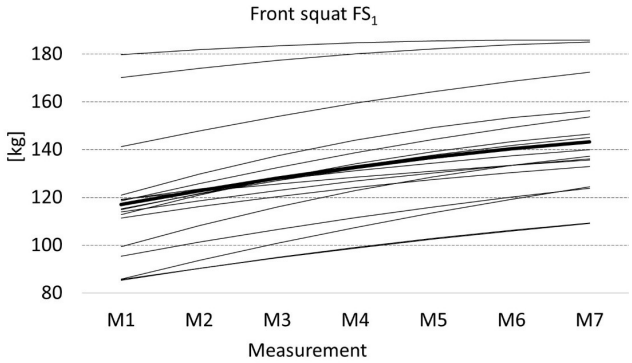


Figure 2. Individual subjects' time trajectories and the average trajectory (thick line)

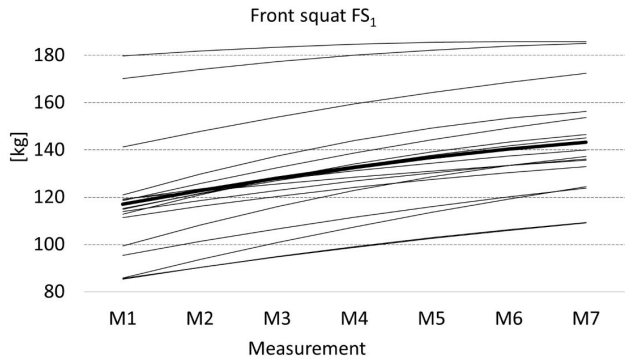


Figure 3. Average time trajectories for both squats for the unconditional model. Vertical bars indicate standard error (SE)

Figure 4 shows the results of the computations for the conditional model FS_2. The interpretation of these graphs is not as obvious as for the unconditional FS_1 model, as the interactions between *Level-1* and *Level-2* proved to be statistically significant. The middle time course refers to individuals for whom the iac variable has a value of zero. This course differs from the mean time course for the FS_1 model, where the values of the intercept, initial trajectory slope and curvature took on successive values of 117.47 kg, 21.67 kg/quarter and -2.85 kg/quarter^2. The conditionality of this finding is further emphasised by the fact that there was no case of *iac* = 0 (mean initial age of 18.6 yrs) among the subjects. The upper FS_{2u} (lower FS_{2l}) trajectories in the graph represent hypothetical time courses for subjects whose *iac* values were greater (16.0 yrs) or lower (21.2 yrs) by one SD (2.6 yrs).

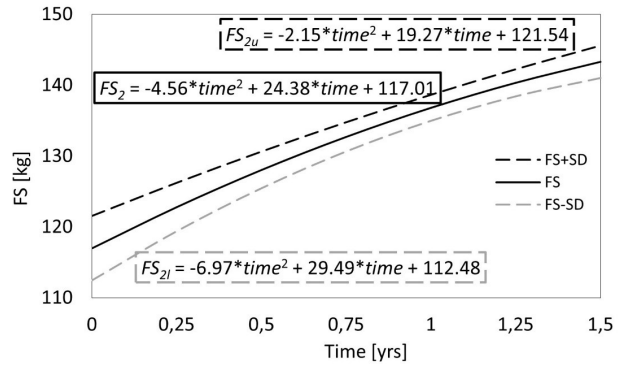


Figure 4. Time trajectories and their analytical forms for the conditional model

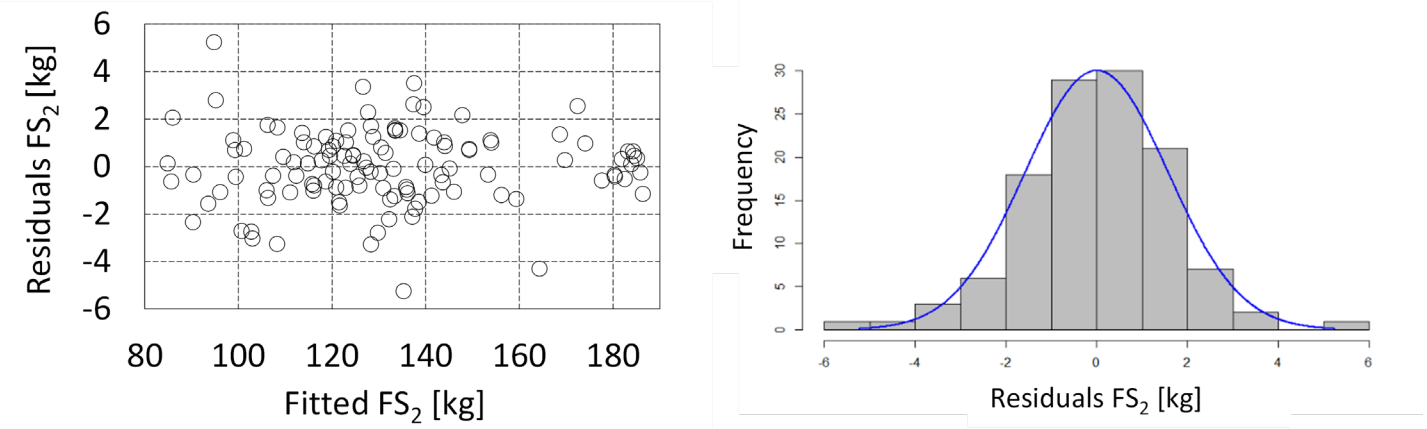


Figure 5. Residuals vs fitted values (left) and histogram of residuals (right) for the conditional model FS_2

Figure 5 presents the results of verifying the two basic assumptions of the regression analysis used in the computations. The uniform distribution of the residuals as a function of fitted values (Fig. 5, left) and their histogram (Fig. 5, right) for the conditional model FS_2 indicate homoscedasticity and a normal distribution of the residuals. This means that the assumptions in question were not violated.

Discussion

The main aim of the present study was to determine the time courses of record scores in the front and back squat achieved by a group of young barbell athletes over a two-year training cycle. The results obtained showed lower record scores for the front squat. The difference in value between the results for both squats appeared to be approximately constant (about 15 kg) over the analysed period. A systematic increase in maximum scores for both squats was observed (Fig. 2). The first statistically non-significant differences between the average values of record scores in successive measurements were only found between the sixth and seventh measurements for both squats. Identical results for the clean were reported in the paper [31].

The initial slope of the time course of record performance in the back squat was found to be greater than in the front squat. This means that there is a greater increase in these records for the back squat during the early training period. Similar observations were documented in [24, 32]. The curvature of the time course for the back squat, on the other hand, was found to be greater compared to the front squat. This is a new finding, indicating that the decline in record scores occurs faster for the back squat.

One of the primary objectives of the present study was also to determine the analytical form of record scores in front and back squats. The results of the calculations showed that it was possible to achieve this goal using an individual growth curve approach. The second-degree polynomial provided sufficient approximation accuracy, as in our previous analyses of record scores in the snatch [26] and the clean [31]. However, it is worth noting that this approximation method was applied for two training macrocycles. Transposing it to longer periods of time, e.g. a weightlifter's entire career [33], may not be effective.

A regression approach was used to model the empirical data. In this approach, one generally builds several models and selects the one (the smallest *-2LL* index value) that most accurately represents the measurement data. The high values of the *-2LL* index for models with random coefficients indicated their limited usefulness in terms of modelling the time course of record performance of young weightlifters, while on the other hand they set a benchmark for more complex models. The prediction quality of the latter FS_l and FS_2, as well as BS_l and BS_2, proved to be at a similar level. Despite the higher *-2LL* values, the simpler unconditional models FS_l and BS_l provided more informative time courses of record scores for both squats.

The FS_2 conditional model allowed additional observations to be made. As previously mentioned, the young weightlifters had at least one year of training behind them. However, the research group included athletes with varying training experience. The time courses of the older athletes, who had more training experience, are less curved and have a lower baseline slope in relation to the reference trajectory (*iac* = 0, Fig. 4). This indicates a stabilised and continuously increasing sporting level. In contrast, younger athletes, being at the beginning of their sporting career, obtained faster improvements in record scores (higher initial slope of the trajectory), but their course is more curved. The apparent increasing deviation from the baseline trajectory (*iac* = 0) indicates the need for changes in the training of younger weightlifters.

When analysing the results obtained, it is important to mention certain limitations that may have affected the quality of the conclusions drawn from the research. These limitations were described in our previous work [26, 31]. It should additionally be noted that the record scores in this study were expressed in kilograms, in contrast to the Sinclair points used in the cited papers. The lack of normalisation of the input data may therefore have increased the standard error of the estimated mean record values, and thus affected the calculation of the significance of differences of adjacent repeated measurements. Nevertheless, the level of this error proved to be acceptable, with the largest value reaching 6.7% for the first measurement (Fig. 3).

Conclusion

Determining the time courses of record scores in the front and back squats makes it easier to assess athletes' skill levels and predict their performance in the next training macro-cycle. Identifying the relationship between these results can improve their use in the long-term training of young weightlifters.

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