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METHOD OF MATHEMATICAL PROCESSING OF RESULTS IN POWERLIFTING FOR DETERMINING THE GREATEST ATHLETES IN THE OVERALL SCORE

Abstract. *Special coefficients and formulas used in powerlifting for determining the strongest powerlifters, regardless of division into bodyweight categories, require changes from time to time for more objective assessment of competitive results among all contestants. Lately, Wilks formula is used for this. However, according to the ratings of the strongest powerlifters calculated using this formula, representatives of light and heavy bodyweight categories predominantly win.*

The purpose of the work is to develop and substantiate a mathematical model that describes the statistical dependence of the results on the weight of the athlete's body.

The analysis of results in the powerlifting total of powerlifters (520 people) and data about their bodyweight according to the materials of IPF World Men's Open Championships for the years 2012 to 2016 was carried out. The mathematical and statistical processing of the materials of the study was conducted and creation of logarithmic regression model based on the least squares method. It is shown that the relationship between the results of competitions in powerlifting and powerlifters bodyweight is best described by the log-linear function. Methods of finding the coefficients of this function are given here. It is proposed to convert powerlifters' competitive results into conventional values with the help of logarithmic coefficients, calculated on the basis of data of previous competitions.

The application of a logarithmic coefficient for calculating relative results in competitions in powerlifting allows to objectively choose the winners in the overall score.

Key words: *powerlifting, logarithmic regression model, logarithmic coefficient formula, overall score.*

Introduction

Methods of determining the physically strongest man are actual for sports. The distribution of athletes in bodyweight categories never took the issue of determining the strongest athlete off from the table. Different tables of coefficients to balance the athlete's body weight and compare the scores of athletes from all bodyweight categories were always proposed. In weightlifting, such calculations are made using the formula proposed by Roy

Sinclair (1985).

The same problem exists in powerlifting too. As some studies show, special coefficients and formulas used in powerlifting to determine the strongest lifters need to be changed from time to time (Schwartz, 2005, Starodubtsev, 1993; Vanderburgh and Batterham, 1999). At different times, calculations were made using different methods, and, as a rule, such formulas were named after the authors: Hoffman, Schwatz, Malone, Glossbrenner, Reshel. Since 1997, the International Powerlifting Federation (IPF) uses the formula proposed by Robert Wilks.

Recent studies (Kotendzhy, 2012; Kotendzhy and Stetsenko, 2009; Stetsenko, 2010) show that, according to the ratings of the strongest powerlifters calculated using the Wilks formula, preference is given to lighter and heavier bodyweight categories, which does not correspond to the proportionality of representation of medium bodyweight categories that are the most numerous. Besides, it has been found that powerlifters with lower body weight show a higher level of relative physical strength compared to other powerlifters (Bal et al., 2010). What is more, the powerlifting stereotype of mostly heavy men lifting extremely large amounts of weights is simply wrong. There is a large amount of variation in both age, weight, and sex (Ball and Weidman, 2016). In addition, other authors argue that there is an uneven relationship between world records and body weight in various powerlifting exercises (Dooman and Vanderburgh, 2000).

The medium bodyweight categories, as a rule, comprise a larger number of talented athletes and are subject to tougher competition. Obviously, the relative level of achievements of such powerlifters should be higher.

Thus, a more objective assessment of the relative performance in powerlifting and determining winners in the overall score requires the working out of new methods to obtain special coefficients.

The working hypothesis of the research is that the development of a mathematical model of the relationship between absolute results and the athletes' bodyweight according to the materials of the world powerlifting championships will allow to objectively determine the winners in the overall score without distribution in bodyweight categories.

The purpose of the paper is to work out a mathematical model describing the statistical dependence of the results of powerlifting to suggest special formula for converting powerlifters' competitive results into conventional units and comparing them in the overall score among all competitors.

Methods

Participants. The paper analyzes powerlifters' competitive results and their bodyweight based on the materials of the IPF Men's World Open Powerlifting Championships, which are available on the IPF official website (http://www.powerlifting-ipf.com/championships/results.html). In total, 520 lifters, who took part in competitions during the years 2012 to 2016, were taken into account.

Indicators were recorded in three competing powerlifting exercises: squat, bench press and deadlift. Performance of such exercises was regulated by the IPF rules, controlled by experts, who were referees.

Statistical Analyses. As a mathematical model describing the dependence of the results athlete's weight, a model of logarithmic regression is suggested. Creation of a logarithmic regression function was made by least squares method. The mathematical and statistical processing of the research materials was performed using the least-squares method by means of Microsoft Excel and Maple software packages.

Results

Analysis of the mathematical type of dependence. It is convenient to consider the qualitative picture of the mathematical dependence of the powerlifting total on a powerlifter's bodyweight using the records in bodyweight categories as an example. The graph of the dependence of Men's World Open records in the powerlifting total using special equipment (as of May 1, 2017) on the powerlifter's bodyweight is shown in Figure 1. The mathematical dependence can be written in the form of an empirical formula, which includes several parameters (Demidovich et al., 2010). According to the characteristic shape of the curve, one can assume that this mathematical dependence has a log-linear form

$$y(x) = a + b \cdot \ln(x), \quad (1)$$

where x is an independent variable that sets the powerlifters' bodyweight;

a, b are constants that are selected in such a way that the curve (equation 1) passes as close to the corresponding points as possible.

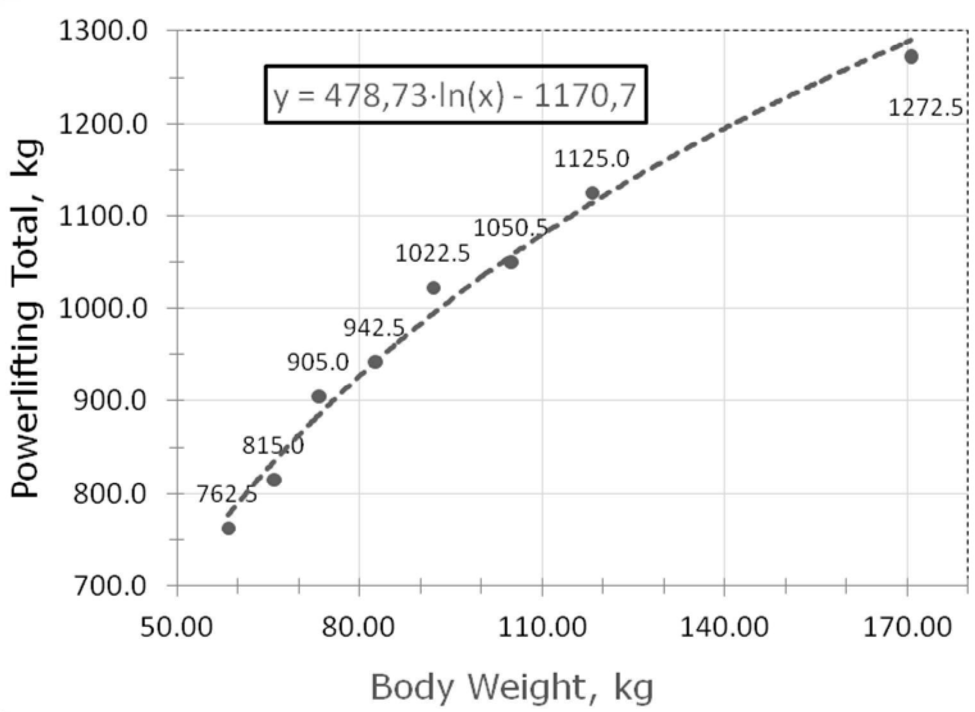

Figure 1. Dependence of IPF Men's World Open powerlifting records in the total with the use of special equipment on the powerlifters' bodyweight

In the graph, the dashed line shows the logarithmic curve, which is created by means of the least squares method in Microsoft Excel (Carlberg, 2006). The equation of the logarithmic curve is given as a function of x. It is obvious that this curve is very close to the values of world records, which are marked by points.

The assumption that the dependence of the results on a powerlifter's bodyweight is log-linear is well consistent with the data from the reference literature. It is known that the relationship between an athlete's muscle strength and his bodyweight is described by the logarithmic function (Zatsiorskiy, 2009).

It is convenient to use a special coefficient to recalculate the results of competitions in order to obtain relative values that allow comparing the achievements of athletes of different bodyweight categories. Hereinafter this recalculation coefficient is called "logarithmic coefficient". Multiplication of the result on this coefficient should bring the value that is on the logarithmic curve, to a certain conventional value that does not depend on the powerlifter's bodyweight. Proceeding from the mathematical notion of the inverse function (Spiegel et al., 2013), the described recalculation is possible, when the logarithmic coefficient is an inverse function of a log-linear dependence (1). This means that the logarithmic coefficient must be equal to a fraction, the denominator of which contains a log-linear dependence (equation 1), and the numerator contains some constant:

$$K_{\log} = \frac{c}{a + b \cdot \ln(x)}, \tag{2}$$

where $K_{\log}$ is the logarithmic coefficient;

c is a constant for valuating the logarithmic coefficient.

If the value of the logarithmic coefficient (equation 2), found as a result of processing of a large number of data of different athletes, is multiplied by the corresponding result of a particular athlete, then ideally we will obtain a relative value that will not depend on the powerlifter's bodyweight. The comparison of such values for different athletes allows us to choose the winner in the overall score.

Finding the logarithmic coefficient of the dependence using the least squares method. Graphically, the results of the participants of the IPF Men's World Open Powerlifting Championships for the years 2012 to 2016 in the total, taking into account powerlifters' bodyweight, that are shown in Figure 2, consist of 520 points, and have certain features:

1. The graph clearly shows that some results lie much lower than the compact data group, and therefore fall sharply out of the general dependence. In order for such abnormal data not to distort the general view of the formula, they must be discarded. The condition for the discarding of such data can be formulated as follows: "If the result of a powerlifter of the next weight category is less than the minimum result of the previous weight category, then this result should be discarded."
2. On the graph, there are vertical groupings of points, which are hereinafter referred to as the "candlesticks". "Candlesticks" are formed at the upper limit of bodyweight categories as a result of the fact that athletes "adjust" their weight to a corresponding bodyweight category. To get the functional dependence, the data grouped into "candlesticks" can be replaced by average values.
3. The logarithmic curve shown on the graph describes well the tendency of increasing the result, when the powerlifter's bodyweight is increased. This increase is unlimited, but the increase of the weight results in the deceleration of the increase in the result, which is a characteristic of a logarithmic dependence. In this case, individual results deviate from the logarithmic curve by almost 30%, which can be explained by different levels of powerlifter's special physical fitness.

The logarithmic curve has an equation, found by the method of least squares (Rawlings et al., 2001) by means of Maple mathematical package (Westermann, 2014):

$$y = -1006.33314 + 411.44557 \cdot \ln(x) \tag{3}$$

Determination of the logarithmic coefficient. To find the logarithmic coefficient in the form of equation 2 we can use the dependence (equation 3). The coefficients *a* and *b* will take the following value:

$$a = -1006.33314;\ b = 411.44557. \tag{4}$$

Then, we should find the valuation rate *c*.

The value of the valuation coefficient can be found for various reasons. For example, the valuation coefficient can be chosen so that the relative result in the powerlifting total corresponds to a value of 1000 kg. Alternatively, one can accept values that are on the logarithmic curve for 100% of the result and bring the relative result in the powerlifting total to a value of 100%. Further, the valuation coefficient was chosen in such a way that relative results in the powerlifting total could be conveniently compared to the corresponding relative values obtained with the help of Wilks coefficient in accordance with the IPF Technical Rules (http://www.powerlifting-ipf.com/fileadmin/ipf/data/rules/technical-rules/english/ IPF_Technical_Rules_Book_2016__1_.pdf).

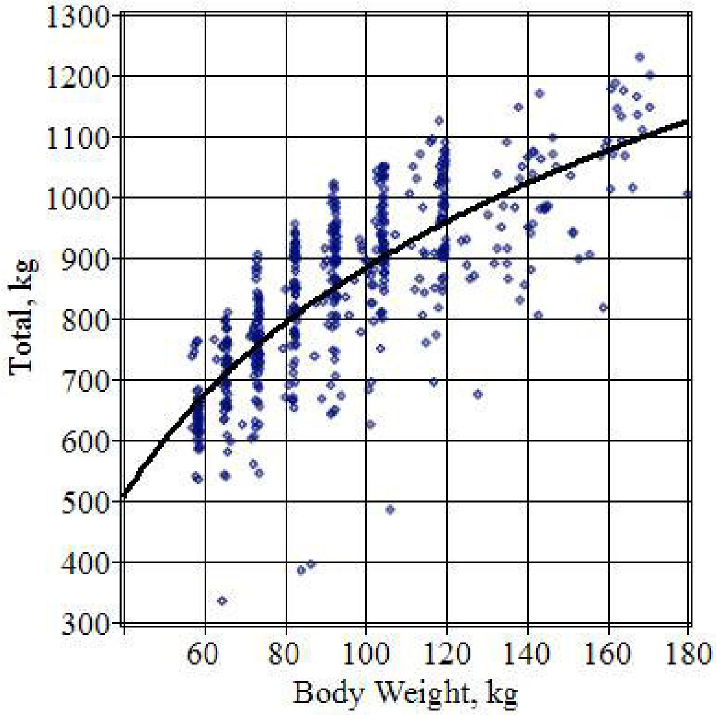

Figure 2. Dependence of the results in the total on the powerlifters' bodyweight

To find the valuation coefficient by analogy with the Wilks formula in the first approximation, we will assume that the c = 500 coefficient, that is

$$K1_{\log}(x) = \frac{500}{-1006.33314 + 411.44557 \cdot \ln(x)}. \quad (5)$$

The graphs of both coefficients are shown in Figure 3, which shows that the curves do not overlap, they have no common points. For the correct comparison of the relative results obtained with the logarithmic coefficient, with the corresponding results obtained using the Wilks coefficient, it is necessary to change the value of the numerator in formula (5) so that the graphs have a common point.

Assume that, so that the Wilks coefficient and the logarithmic coefficient have the same value for the average bodyweight of lifters, who participated in the IPF Men's World Open Powerlifting Championships for the years 2012 to 2016.

The average weight of the participants of the competition is

$$x_{cp} = 95.290203 . \quad (6)$$

Now the adjustment coefficient s should be found from the equation

$$s \cdot K1_{\log}(x_{cp}) = Wilks(x_{cp}), \quad (7)$$

where $Wilks(x_{cp})$ is the Wilks coefficient value for a powerlifter with a bodyweight of $x_{cp} = 95.290203$ kg.

After performing the calculations we obtain the value of the correction coefficient:

$$s = 1.07909587 . \quad (8)$$

After substituting the found value into the equation

$$K_{\log}(x) = s * K1_{\log}(x), \quad (9)$$

we obtain a refined formula, which will determine the logarithmic coefficient

$$K_{\log}(x) = \frac{539.547934}{-1006.33314 + 411.44557 \cdot \ln(x)} . \quad (10)$$

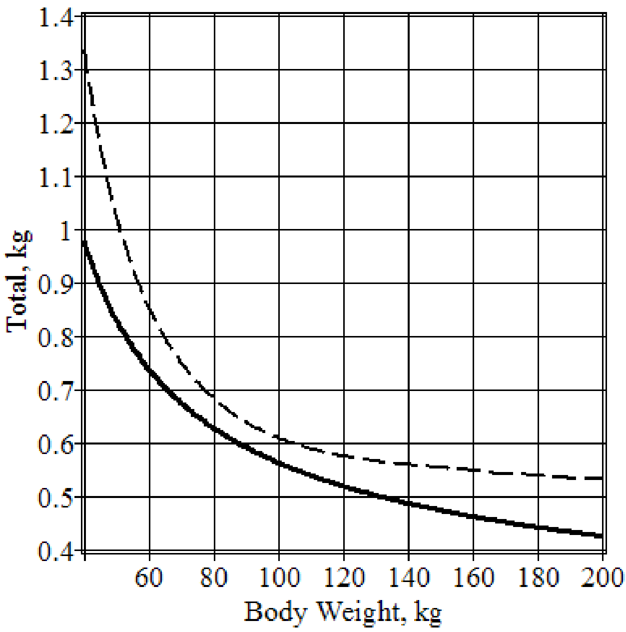

Figure. **3.** Dependence of Wilks coefficient (dashed line) and the first approximation of the logarithmic coefficient (solid line) on powerlifters' bodyweight

Discussion

Nature of the dependence of competitive results on powerlifters' bodyweight. It is generally recognized that for persons of approximately the same level of physical fitness, but of different bodyweight, the absolute muscular strength increases with the increase in bodyweight, but the relative muscle strength decreases. The decrease in the relative muscle strength is due to the fact that a powerlifter's bodyweight is proportional to the volume of the body (the cube of his linear dimensions); and the strength is proportional to the physiological section of the muscles (square of linear dimensions). Therefore, the mathematical dependence of strength on bodyweight in theory should be of a logarithmic nature (Zatsiorskiy, 2009).

Cleather (2006) supports the thought about the nonlinearity of the dependence of the result on bodyweight. Equations for each powerlifting exercise and broken down by gender received by him by using regression analysis are of allometric (exponential) nature. At the same time, Batterham and Keith (1997) suggest applying the allometric function as an additional tool for scaling the differences in results only, depending on the body size. Investigating the dependence of the results on powerlifters' bodyweight, Marković and Sekulić (2006) identified gender differences and different values of the power coefficient of the exponential function for various bodyweight categories. Obviously, the level of manifestation of maximum muscle strength is influenced, in addition to an athlete's anthropometric data, by a number of important functional indicators of different systems of his body. With relatively identical height-and-weight indicators, powerlifters can demonstrate different results, both in total and in the same exercises.

Recently, scholars (Bishop et al., 2017; Haleczko, 2014, 2015; Haleczko and Korzewa, 2016), who suggested a new approach to determine winners in the overall score, conduct researches quite intensively. However, some of the conclusions are generated by them as a result of data calculations for 20 to 50 cases, which is, in our opinion, insufficient.

Comparison of powerlifters' relative results obtained by using the Wilks formula and the logarithmic coefficient formula. The analysis of the distribution of prize-winning places in the overall score between participants in the IPF Men's World Open Powerlifting Championships for the years 2012 to 2016 shows that the best indicator is shown by representatives of the lightest bodyweight category (up to 59 kg). In all of these championships (5 cases out of 15, that is 33.3%), namely the representatives of this bodyweight category were among the prize winners. Besides, in 4 championships out of 5 (80%) they took the 1st place. Representatives of the heaviest bodyweight category (over 120 kg), as well as those of the light bodyweight category, were prize winners in all the championships. At the same time, representatives of bodyweight categories up to 66, 74, 83 and 93 kg appeared there only once (6.7%). Powerlifters of bodyweight categories of up to 105 kg and up to 120 kg were never found in such lists, although, according to the quantitative membership of competitors, namely in the bodyweight category of up to 105 kg, the highest indicator was recorded – 15.38% of the total number of competitors, and the bodyweight category of up to 120 kg has the third indicator – 14.38% (Table 1). Such a discrepancy, in our opinion, allows us to doubt the objectivity of choosing the best powerlifters in the overall score by using the Wilks formula.

Table 1. Number of participants of the IPF Men's World Open Powerlifting Championships for the years 2012 to 2016.

Weight Category	2012	2013	2014	2015	2016	Total participants	
						number	%
Up to 59 kg	10	7	11	9	12	49	8.19
Up to 66 kg	13	10	8	10	14	55	9.20
Up to 74 kg	16	15	14	17	11	73	12.21
Up to 83 kg	21	10	16	13	17	77	12.88
Up to 93 kg	21	18	19	17	15	90	15.05
Up to 105 kg	20	12	19	22	19	92	15.38
Up to 120 kg	16	16	20	16	18	86	14.38
More than 120 kg	16	18	12	17	13	76	12.71

Figure 4 shows graphs of the Wilks coefficient and the proposed logarithmic coefficient and the ratio of the logarithmic coefficient to the Wilks coefficient $\frac{K\log}{Wilks}$. The values of the Wilks coefficient increase significantly with low values of a powerlifters' bodyweight, which give preference to powerlifters of light bodyweight categories. The graph of the ratio of the logarithmic coefficient to the Wilks coefficient allows to better understand differences between these coefficients.

For average weight of $x_{cp} = 95.77664773$ kg, the values of both coefficients are the same, and for light and heavy bodyweight categories they differ by 10% or more. Moreover, the more steep decline of the curve of the ratio of coefficients is observed in the range of light bodyweight categories, to which Wilks coefficient, as it has already been mentioned, gives a significant advantage.

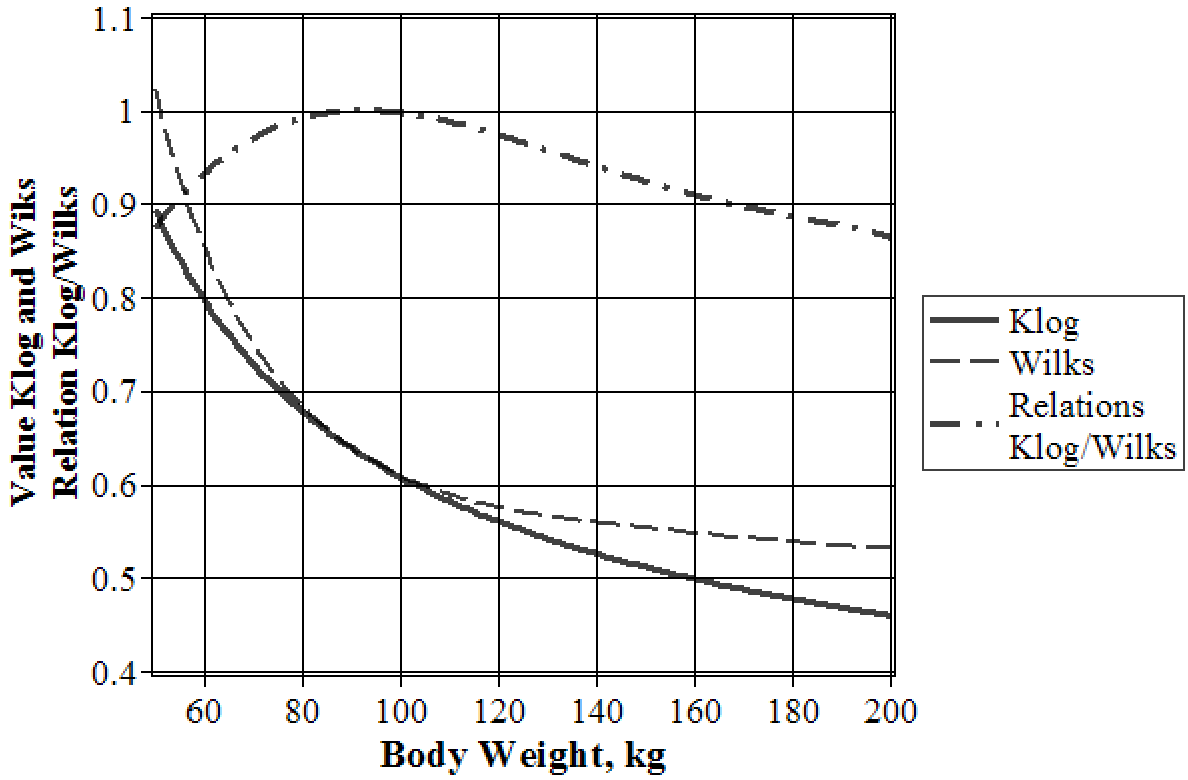

Figure 4. Comparison of the values of the logarithmic coefficient Klog and the Wilks coefficient depending on a powerlifter's bodyweight

Anthropometric characteristics (weight and length of the body, fat layer) and a powerlifter's structure can affect his competitive results (Evangelista et al., 2015). In order to achieve a greater value by using Wilks formula, an athlete needs to have a larger muscle size (Keogh et al., 2009; Ye et al., 2013). However, for sportsmen of heavier bodyweight categories, the need to reduce body weight to the limits of bodyweight categories is less relevant, so the relative influence of their muscular component on the competitive result may be not so strong. The logarithmic coefficient automatically takes into account such a feature, and as a result, the values of heavyweight athletes' relative results may deteriorate, which gives them lower positions in the overall score.

The objectivity of the suggested approach may be approved by comparing the relative results calculated with the help of the logarithmic coefficient, with similar results obtained by using Wilks coefficient. While applying the suggested approach, the results and the distribution of places in the overall score change significantly with the alignment of opportunities of different bodyweight categories (Fig. 5). It is seen that when calculating the relative results with the help of the logarithmic coefficient, the values on the edges, that is, in light and heavy bodyweight categories, change significantly. It turns out that athletes of those bodyweight categories that are less numerous do not receive an advantage in the overall score. For example, according to the results of 2016 Open World Championships, representatives of bodyweight categories of up to 93, 74 and 120 kg could be among the top three winners.

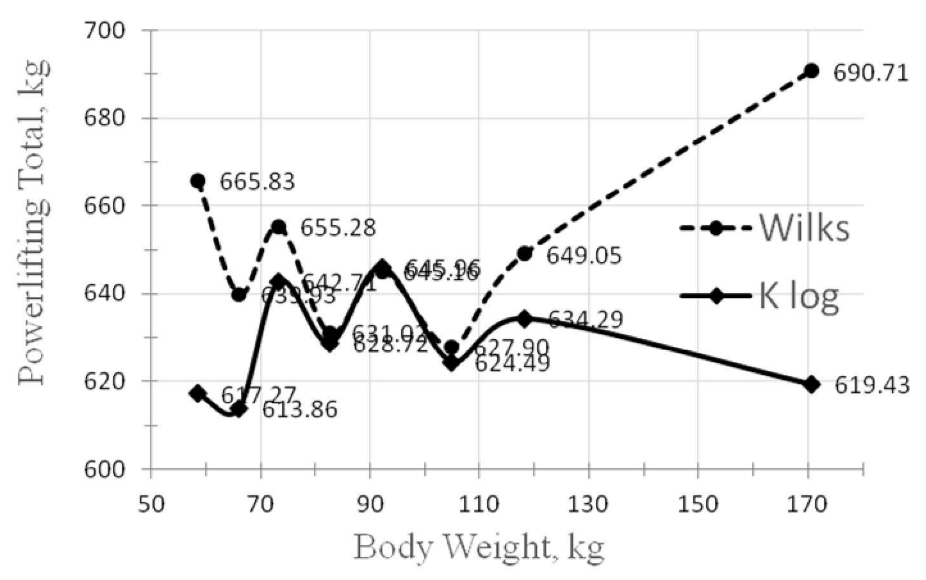

Figure 5. Comparison of values of men powerlifting world records in the powerlifting total with the use of special equipment according to the Wilks coefficient and the logarithmic coefficient $K_{\log}$

Conclusions

The findings of this study suggest that the Wilks coefficient used in powerlifting for determining places of competitors in the overall score, regardless of the weight, may not be considered objective due to unreasonable dominance of representatives of light and heavy bodyweight categories. The present study provided a novel analysis to convert powerlifters' competitive results into conventional units using the logarithmic coefficients calculated on the basis of mathematical and statistical processing of data of previous competitions. This allows the representatives of the most numerous bodyweight categories to be among the top three in the overall score. The proposed methods for finding the formula of the logarithmic coefficient based on mathematical model of logarithmic regression allows to periodically refine this coefficient on the basis of updated data of competitive results powerlifters.

By using analogous methods, the values of logarithmic coefficients for different categories of competitions can be determined (by gender and age groups, separate bench press competitions, competitions with or without the use of special equipment, etc.) as well for different categories of competitions in weightlifting.

Since authors studied only two indicators (bodyweight and result in the total), our results may be somewhat biased, and therefore require more extensive research.

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Conflict of interest. The authors state that there is no conflict of interest.

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МЕТОДИКА МАТЕМАТИЧНОЇ ОБРОБКИ РЕЗУЛЬТАТІВ У ПАВЕРЛІФТИНГУ ДЛЯ ВИЗНАЧЕННЯ НАЙКРАЩИХ АТЛЕТІВ ЗА ЗАГАЛЬНОЮ ОЦІНКОЮ

Анотація. Вступ. *Метою роботи є розробка та обґрунтування математичної моделі, яка описує статистичну залежність результатів спортсмена від ваги тіла.*

Робоча гіпотеза дослідження полягає у тому, що розробка математичної моделі взаємозв'язку між абсолютними результатами та вагою спортсменів, відповідно до матеріалів чемпіонатів світу з пауерліфтингу, дозволить об'єктивно визначати переможців у загальному заліку без розподілу по вагових категоріях.

Методи. *У роботі аналізуються результати змагань пауерліфтерів та їх маса тіла на основі матеріалів Міжнародного чемпіонату світу з пауерліфтингу серед чоловіків, які можна знайти на офіційному веб-сайті IPF (http://www.powerlifting-ipf.com/championships/ results.html). Загалом було враховано результати 520 пауерліфтерів, які брали участь у змаганнях з 2012 по 2016 роки.*

У якості математичної моделі, яка описує залежність результатів атлетів від їх ваги, пропонується модель логарифмічної регресії. Визначення функції логарифмічної регресії було зроблено методом найменших квадратів. Математична та статистична обробка дослідницьких матеріалів проводилась методом найменших квадратів за допомогою пакетів програм Microsoft Excel та Maple.

Результати. *Антропометричні характеристики (вага і довжина тіла, жировий шар) і структура тіла пауерліфтера можуть впливати на його результати змагання. Для того, щоб досягти більших результатів за допомогою формули Вілкса, спортсменові потрібно мати більший розмір м'язів. Проте для спортсменів у важких вагових категоріях потреба у зниженні маси тіла до межі вагової категорії є менш актуальною, тому відносний вплив їх м'язової складової на результат змагань може бути не таким сильним. Логарифмічний коефіцієнт автоматично враховує таку особливість, і у підсумку значення відносних результатів спортсменів у важкій вазі можуть погіршуватися, що дає їм нижчі позиції в загальному рахунку.*

Об'єктивність запропонованого підходу може бути підтвердженою шляхом порівняння відносних результатів, розрахованих за допомогою логарифмічного коефіцієнта, з подібними результатами, отриманими за допомогою коефіцієнта Вілкса. При застосуванні запропонованого підходу результати та розподіл місць у загальному заліку значно змінюються з вирівнюванням можливостей у різних вагових категоріях. Аналіз наведених графіків показує, що при обчисленні відносних результатів за допомогою логарифмічного коефіцієнта значення на межі, тобто у легких і важких вагових категоріях, значно змінюються. У результаті, спортсмени з менших вагових категорій не отримують переваг у загальному рахунку. Наприклад, згідно з результатами Відкритого Чемпіонату Світу 2016 року представники вагових категорій до 93, 74 і 120 кг можуть бути серед трьох переможців.

Висновки. *Результати цього дослідження свідчать, що коефіцієнт Вілкса, який використовується у пауерліфтингу для визначення місць конкурсантів у загальному заліку, незалежно від ваги, не може вважатися об'єктивним через необгрунтоване домінування представників легких та важких вагових категорій. Дане дослідження представило новий аналіз для перетворення конкурсних результатів поуерліфтерів у одну шкалу з використанням логарифмічних коефіцієнтів, розрахованих на основі математичної та статистичної обробки даних попередніх змагань. Це дозволяє представникам найчисленніших вагових категорій посідати перші місця у загальному заліку. Запропоновані методи пошуку формули логарифмічного коефіцієнта на основі математичної моделі логарифмічної регресії дозволяють періодично уточнювати цей коефіцієнт на підставі оновлених даних результатів змагань пауерліфтерів.*

Використовуючи аналогічні методи, можна визначити значення логарифмічних коефіцієнтів для різних категорій змагань (за статтю та віковими групами, окремі стендові пресові змагання, змагання з використанням або без використання спеціального обладнання тощо) у важкій атлетиці.

Ключові слова: *пауерліфтинг, логарифмічна регресійна модель, формула логарифмічного коефіцієнта, загальна оцінка.*

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ЗАСТОСУВАННЯ ПОПЕРЕДНЬОЇ ОБРОБКИ ЗОБРАЖЕНЬ ІЗ РАСТРОВОГО ЕЛЕКТРОННОГО МІКРОСКОПА ДЛЯ ПОКРАЩЕННЯ ІДЕНТИФІКАЦІЇ СТРУКТУРНИХ ЕЛЕМЕНТІВ*

Анотація. *У роботі описано вплив попередньої обробки зображень чотирифазного зразка системи Cu-Sn, що отримані із растрового електронного мікроскопа, на аналіз структурних елементів. Попередня обробка зображень здійснювалася методами Гаусового та нерізкого розмиття. Описано алгоритм обробки зображень з застосуванням матричних*

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