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THE OPTIMAL LOAD FOR ACHIEVING MAXIMUM OUTPUT POWER – BENCH PRESS FOR TRAINED ATHLETES

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SUMMARY

This study is focused on finding the optimum load weight needed for the maximum mechanical power output during pressure exercise on a bench (bench press). The main objective is to identify the maximum load weight (% 1*RM*), with which the sample reaches the maximum mechanical power output (% $P_{mm)}$ during bench press exercise (BP). Results are recorded separately during the measurement and can help to determine the optimal load during strength training.

A group of 15 highly trained athletes took part in the research, examined using experimental methods and measured with 3D kinematic and dynamic motion analysis. The group performed strength test with mechanical power output being easured at 0, 10, 30, 50, 70, 90 and 100% of one – recurrent maximum (1*RM*). Determined data was edited in Qualisys Track Manager and Visual Basic 3D / RT (C-Motion, Rockville, MD, USA) software.Maximal mechanical power output during the bench press exercise was achieved in the set of test subjects with a relative percentage of the load weight equal to 52% of 1*RM*.

Key words: optimal weight load, output power, kinematic motion analysis, dynamic motion analysis, 3D motion analysis

INTRODUCTION

In the collective ball games, explosively oriented athletic disciplines and in many other sports it is necessary to produce the maximum amount of mechanical work in the shortest possible time in certain situations. This means that it is necessary to achieve high mechanical power output. Performance is a mechanical variable defined as speed of the work and can be expressed as the amount of work done per unit of time or as a product of power and speed. Performing the task is largely influenced by how much power is applied to objects (eg to the ground, ball, sports equipment). Newton and Kraemer (2000) suggest that in the explosively-oriented sports the mechanical power output is one of the most important performance factors. Better understanding of the mechanical energy release rate depending on the load for specific exercises allows us to streamline the optimal load for strength training of various areas (Jandačka, 2008).

The mechanical power output is dependent on the external load, which acts via force against a movement (Hill, 1938). A. V. Hill (1938) was the first to cover the relationship between muscle performance and load. Based on his experiments, in which he at first examined isolated frog muscles, he provided the optimum ratio of muscle force F and maximum muscle force F_{mm} to achieve maximum muscle power P_{mm} during concentric contraction with value of F_{opt} / F_{mm} = 0.31. The optimal value of power is thus 1 / 3 of maximal isometric muscle force at maximum power. Kaneko et al. (1983) states that a strength training with a load that maximizes muscle performance helps the development of mechanical muscle performance in flexion at the elbow joint. The optimum load for maximized mechanical performance during specific exercises of upper limbs was investigated by Wilkie (1950), Baker, Nance and Moore (2001a), Baker, Nance and Moore (2001b), Siegel, Gilders, Staron and Hagerman (2002), Kawamori et al. (2005), Kilduff et al. (2007), Cormie, McCaulley, Triplett and McBride (2007b) and Thomas et al. (2007).

Individual authors, however, present very different values of the optimal load. The optimal load in individual studies varies between 0 and 80% 1*RM*. Research is carried out using methods that simplify the measurement method to the point where the results cannot be valid. Unlike the earlier method FitroDyne Premium which used to be used with this issue, the 3D motion analysis QUALISYS method, which will be used for the present measurements, is able to capture dumbbell's movement in all axes x, y and z. Unlike earlier methods (Cormie et al., 2007), we are able to get the speed of any point, e.g. centre of gravity of the upper limbs of tested person and load, and not only monitor the speed of the dumbbell as it used to be in the previous method of measurement.

METHODS

Set

A homogeneous group of 15 trained athletes participated in this study. The average age of test subjects was (26.1 ± 3.87) years in the interval from 19 to 33 years, mean body height (183.3 ± 6.73) m in the interval from 1.70 to 1.96 m and the average body weight (78.8 ± 7.17) kg in the interval from 65 to 91 kg. The basic set is a population of trained athletes who have no serious health problems that might limit the bench press exercise.

Experimental setup

For the range of motion during BP exercise the FitroDyne Premium device was used. This device uses the principle of optical encoders. FitroDyne Premium (FDP) is a system designed to diagnose force ability and to control feedback of the load training. FDP sensor is connected to the loading rod of a multipress and displays basic biomechanical parameters (vertical movement speed of a loading dumbbell) (Jandačka,

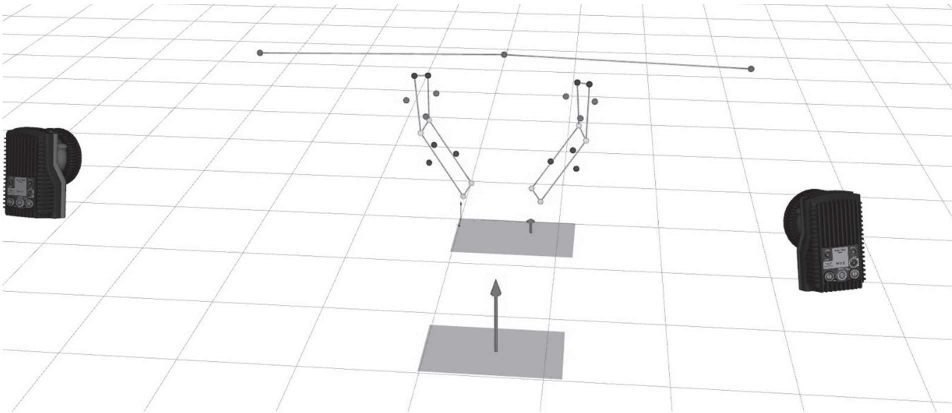

Figure 1. Qualisys system uses its own high-precision cameras for tracking a measured object using passive or active markers in 3D.

Vaverka and Gajda, 2006) in graphic and digital form using the computer system. A range of motion was set for each tested person with the FDP by using a mechanical goniometer according to Zatsiorsky and Kraemer (2006). The tested person (TP) heard a beep from the speaker when he had to change the downward movement to the upward movement. Performance testing was carried out using exercises with free dumbbell (without guide rails).

An optoelectronic system using infrared reflection from the reflective markers placed on the body (Figure 1) was used for the 3D kinematic motion analysis. Three-dimensional motion data of the upper limbs was scanned with a frequency of 247 Hz during "bench press" exercise using seven-camera system for movement recording (Qualisys Oqus, Sweden). This device provides kinematic data very quickly and with high precision. 25 fluorescent points were fixed on the test subjects, continuously scanned by cameras. To measure the contact forces between the bench and the pad during the lift there were two force-measuring platforms (Kistler 9281CA and 9286AA, Switzerland) used embedded in the floor under the bench and sampling data with a frequency of 988 Hz. The benches were connected to a PC via the AD converter and synchronized with 7 cameras.

Protocol

Test subjects participated in two different measurements in two days at least one week apart each other. Range of motion of each tested person was set without touching the chest (chest – touch position) and was controlled by an audio signal in the lowest and highest point of the trajectory. The first visit included testing the maximum performance in a single repetition following the protocol published by Kraemer, Ratamess, Fry and French (2006). After a brief instructioning about the correct exercise implementation the primary information required from each athlete was their subjective 1*RM*. This was followed by heating 5 to 10 repetitions with 40 to 60% of the load weight of their subjective 1*RM*. After a 3 minutes rest the load weight was increased to 80% of their subjective 1*RM*. Subsequently, the real value of their 1*RM* (deviation ± 6 kg) was found according to the achieved results, using the following equatio (Adams, 1998).

$$1\ RM = \frac{\text{repwt}}{(1 - 0.02\ \text{reps})}$$

1RM – one repetition maximum
repwt – 80% of subjective 1RM
reps – number of repetitions

The second measurement took place in the morning. It was important to instruct TP that they may not eat or drink about 4 hours and also not consume any alcoholic beverages about 24 hours before this measurement. A body composition was determined using bioimpedance method (TANITA 418 MA, USA). A percentage of fat, water and muscle mass in specific areas important for this study (body height, body weight and weight of segments of the upper limbs and trunk) were also determined. Among the important factors in the BP exercise was one short 5 minute warm-up to eliminate the possibility of TP injury. Subsequently the clusters and markers were attached on TP. When measuring P_{mm} the load weight with which the exercises was carried out was systematically increased by 0, 10, 30, 50, 70 and 90% of their actual 1 *RM*. To calculate 0% of 1*RM* only a bare weight of TP's upper limbs was considered. With each such load TPs performed a lift with the maximum possible speed. There was at least 3 minute interval between each lift. The measurement was performed three times with each load for each TP. If the loss of one of the markers occurred during the test, both in the computer program or directly from TP, the measurement had to be repeated. At the end the markers and clusters removal took place as well as individual stretching.

Data Analysis

Performance (W) was calculated as the product of vertical force (N) and vertical velocity (ms^{-1}) of CG (center of gravity of a system consisting of segments of the upper limb and dumbbell). The speed of CG (ms^{-1}) was a parameter calculated using Visual 3D software. To determine the CG of the body we use a knowledge its segments CG, from which a model for the given motion activity is created. We understand the CG of the body as the action point of gravity forces acting on the human body. Currently, the CG is most commonly determined using the so called analytical method that allows the use of algorithms applicable to a wide range of physical activities. Data obtained using the optoelectronic system was processed by Visual 3D software (C-Motion, Rockville, MD, USA). All segments of the upper limbs except the hands were modeled as truncated cones, while the dumbbell was modeled as a cylinder. A fitness bench generated a vertical force by acting on four points of platforms. Vertical force (N) was obtained as a sum of two signals from two force-measuring platforms detecting vertical forces acting on the pad (N) and weight of the upper limbs (N). The weight of the upper limbs (N) was calculated by multiplying the weight of the upper limbs (kg) by gravity acceleration

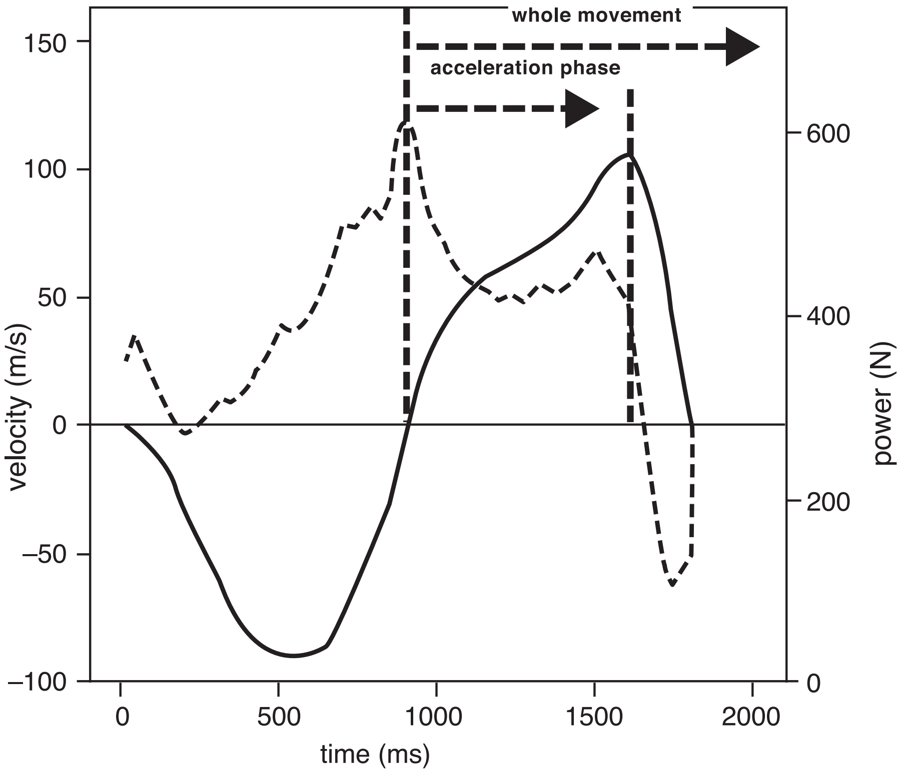

Figure 2. Relationship between velocity (*v* – full curve), force (*F* – dashed curve) and time *t*, during a bench press exercise (TP – man) with 40 kg load (Jandačka & Vaverka, 2008a).

(ms^{-2}). Performance is expressed as a function depending on the track (range of motion) and was determined for each lift with each load. Using the course of velocity (ms^{-1}) of CG and its derivative the acceleration and deceleration phases of movement up (lift) (Figure 2) were determined. Thus the average performance was determined for each lift with each load (% 1*RM*) of the entire movement with a positive performance and also of the acceleration phase of movement. Maximum performance (W) was the absolute maximum for all loads.

Statistical analysis

Optimal load will be determined using optimization of a regression function, which will satisfactorily explain the measured dependence of power on the load. Tightness of the relationship between regression model and measured data will be determined by determination coefficient (R2). Basic statistical characteristics will be used as well in this work. The optimum value of load is sought as a local maximum of the regression function. Reliability of measurement of mechanical performance of muscle was estimated using inter-class correlation coefficient (ICC). The analysis was calculated in the SPSS 15th program.

RESULTS

The greatest standard deviation from the average load weight was achieved in the diagnostics of muscle performance, amounting to 0% 1 *RM*. The size of the standard deviation gradually declined, reaching the lowest values with the load weight 90% 1 *RM* (Figure 3).

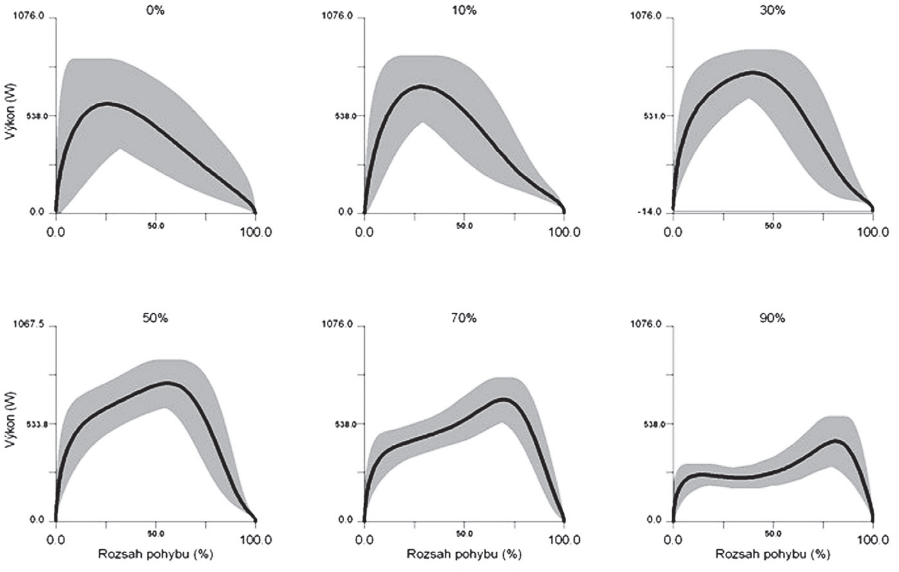

Figure 3. Relationship between vertical component of performance (W) and range of motion (%). The solid line represents the average mechanical performance output for a given load weight (% 1*RM*) during the bench press exercise. The gray color shows the standard deviation of muscle performance (interindividual). (N = 15, each athlete performed three test with each load, experiment with the best performance was used for subsequent analysis).

A.V. Hill (1938) suggested a relationship between stress and performance. That is why there has been used a quadratic regression equation here, where we can observe the relationship between the ratio of output mechanical performance (Pmax%) and load weight (% 1*RM*) during the bench press exercise (Figure 4).

Values of mechanical output performance with individual load weight % and their standard deviations are presented in (Figure 5). The highest value of mechanical output performance was achieved with 50% of the load weight. Subsequent research should show whether the results were significant.

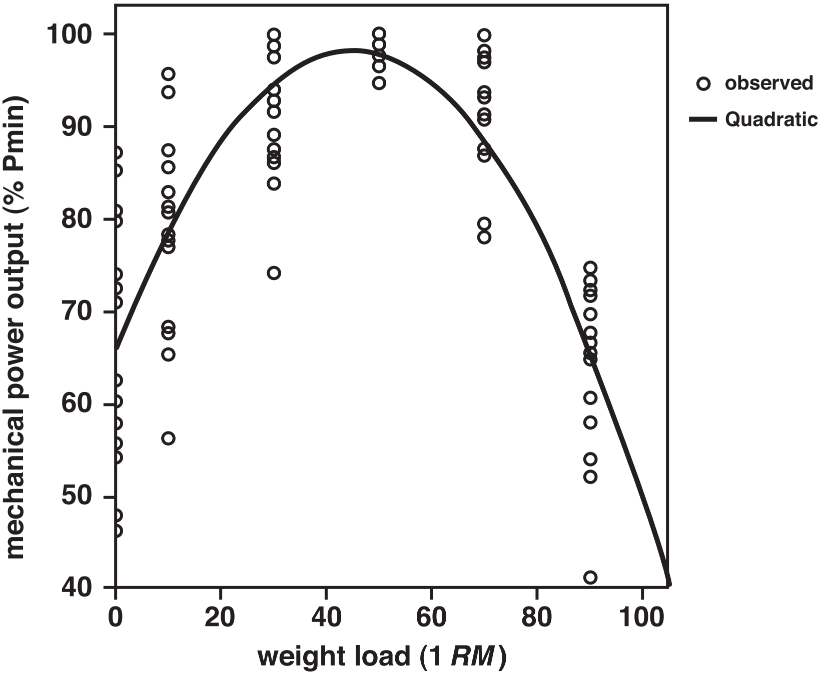

Figure 4. The relationship between the ratio of mechanical output performance (Pmax%) and load weight (% 1*RM*) lifted during the bench press exercise. Circles represent the observed data. Full curve represents the quadratic regression model.

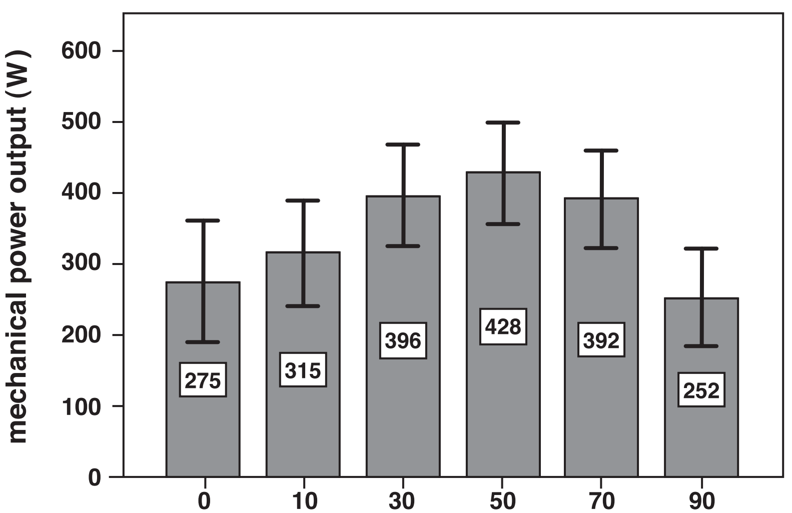

Figure 5. The relationship between the vertical component of mechanical output performance (W) and load weight (% 1*RM*).

DISCUSSION

The importance of this study is in determining how to measure the maximum mechanical output performance using 3D movement analysis and strain-gauge platform. Optimum load weight for maximum mechanical output performance appearing in present literature is in the range from 0–80% 1*RM* (Baker, Nance and Moore, 2001), (Cormie, McCaulley, Triplett and McBride, 2007b), (Thomas et al., 2007). However, the research is currently carried out using methods that simplify the measurement method so that results cannot be valid. One of the main goals of this work is to verify the validity and reliability of mechanical output performance measurement and to achieve more accurate results for the performance of 1RM using the latest techniques (3D analysis). We validated measuring of the maximum mechanical performance of muscles using 3D Qualisys analysis. This method achieves more accurate results due to the fact that compared to previous methods (Cormie et al., 2007), we are able to get the speed of CG of upper limbs in all axes of both the tested person and the load. Reliability is estimated in the classical testing theory by a reliability coefficient r, which is the proportion of true variance to observed variance. The reliability coefficient r expresses the degree to which measurement errors increase the real variance and also the level of balance of real performance as well as actual levels of physical abilities and skills with respect to the balance of observed performances in the test set (Měkota, Blahuš, 1983 in Jandačka, 2008). The coefficient of reliability can also be expressed as inter-class coefficient (ICC) using analysis of variance ANOVA and denoting it R (Alemany et. al., Jandačka in 2005, 2008). Resulting inter-class coefficient (ICC) of highly trained athletes achieved in this work has the value of ICC = 0.99. This value indicates that the reliability of measurement of maximum muscle performance is probably high. Typical error of measurement s = 32.3 W.0, 10, 30, 50, 70, 90% of TP's actual 1 RM was calculated to achieve the mechanical output performance. They executed a lift with each thus calculated load with maximum speed and this measurement was performed three times for each TP. There was at least 3 minutes interval between the lifts. It is important to realize that with light load weights test the subjects produced the maximum instant output performance mainly in the first half of the motion range, while with the heavier load the maximum muscle performance moved into the second half of the motion range (Figure 3). The muscles work in different phases of movement in closely relation to lifted load weight. The force developed by the TP has been measured as a reaction force via dynamometric platforms. The performance was then calculated as the product of speed and force. Performance is expressed as a function depending on the relative track (motion range).

CONCLUSIONS

From the overall achieved results we could identify the relative load weight with which the athletes achieved maximum mechanical output performance. Each performed test had to meet the basic requirements, i.e. reliability and validity. Reliability of measurements of the maximum mechanical output performance was determined by repeating the test. This research revealed the reliability of measurement of maximum muscle mechanical performance using inter-class correlation coefficient, which reached values of ICC = 0.99. Verification of validity of measurement of the maximum mechanical output performance using the 3D analysis Qualisys is a result of the fact that the above method is able to capture not only the movement of a dumbbell in all axes x, y and z, but we also get the speed of CG of the TP's upper limbs and the load unlike only the speed of a dumbbell as it did in the previous method of measurement (Cormie et al., 2007).

The maximal mechanical output performance in the bench press exercise was achieved in the set of test subjects with a relative percentage of the load weight equal to 52% maximum of 1RM. The value of the load could be an optimal training load for non-ballistic training in which we try to produce maximum energy in the shortest possible time.

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OPTIMÁLNÍ ZÁTĚŽ PRO DOSAŽENÍ MAXIMA VÝSTUPNÍHO VÝKONU – BENCH PRESS U TRÉNOVANÝCH SPORTOVCŮ

RICHARD BILLICH, KAREL JELEN

SOUHRN

Tato studie je zaměřena na hledání optimální hmotnosti zátěže, se kterou je dosahováno maximálního mechanického výstupního výkonu během cviku tlak v lehu na lavičce (bench press). Hlavním cílem je identifikovat maximální hmotnost zátěže (% 1RM), se kterou výběrový soubor dosahuje maximálního mechanického výstupního výkonu (% Pmm) při cvičení bench press (BP). V průběhu měření jsou výsledky jednotlivě zaznamenány a mohou pomoci ke stanovení optimální zátěže při silovém tréninku.
Výzkumu se zúčastnila skupina patnácti vysoce trénovaných sportovců. Za použití experimentálních metod a měření pomocí 3D kinematické a dynamické analýzy pohybu. Skupina vykonávála silový test, u kterého byl měřen mechanický výstupní výkon s 0, 10, 30, 50, 70, 90 a 100 % jednoho – opakovacího maxima (1RM). Determinovaná data byla upravována v programech Qualisys Track Manager a Visual 3D Basic/RT (C-motion, Rockville, MD, USA). Při cvičení bench press bylo maximálního mechanického výstupního výkonu dosahováno u souboru testovaných osob, s relativním procentem hmotnosti zátěže 52 % jednoho opakovacího maxima.

Klíčová slova: optimální zátěž, výstupní výkon, kinematická analýza pohybu, dynamická analýza pohybu, 3D analýza pohybu

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