A SIMPLE SYSTEM FOR MONITORING OF WEIGHT EXERCISE - APPLICATION IN ASSESSMENT OF STRENGTH ABILITIES

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Abstract:

In order to monitor force and power produced during a weight exercise a simple computer based system has been designed. Utilizing Newton's laws of mechanics the actual force while lifting the weight can be derived by multiplying mass and acceleration. The latter is being obtained as a derivation of velocity registered by means of a sensor mechanically coupled with a barbell. Multiplying the force and velocity provides the actual value of power. The system provides on-line graphical and digital data and calculates mean and maximal values separately for the eccentric and concentric phase. Monitoring the basic biomechanical parameter during repetitions with stepwise increasing weights up to 1RM performed with maximal effort in the concentric phase provides data to draw individual force-velocity and power-velocity curves. These allow the estimation of strength and power at different velocities as a basis for a more sports specific assessment of strength abilities.

Key words: muscular strength, muscular power, force-velocity curve, power-velocity curve, strength testing

Zusammenfassung:

EIN EINFACHES SYSTEM ZUM BEWERTEN DES GEWICHTTRAININGS- -DIE ANWENDUNG BEI DER BEWERTUNG VON KRAFTFÄHIGKEITEN

Mit dem Ziel, die bei den Gewichtsübungen ausgeübte Kraft und Leistung zu messen, wurde ein einfaches Computersystem entwickelt. Aufgrund der Newtonschen Gesetze der Mechanik kann die eigentliche bei den Gewichtsübungen ausgeübte Kraft gerechnet werden, indem man Masse mit Akzeleration multipliziert. Die Akzeleration wird als Derivation der Geschwindigkeit bestimmt, die mittels eines mit der Hantel mechanisch verbundenen Sensors gemessen worden ist. Das Produkt der Kraft und Geschwindigkeit gibt den realen Wert der Leistung.

Das System ermöglicht on-line graphische und digitale Darstellung der Daten und rechnet Mittel- und Gipfelwerte besonders für die exzentrische bzw. konzentrische Phase aus.

Verzeichnet man die biomechanischen Grundparameter während Wiederholungen, wobei die Belastung stufenweise bis zum Maximum (1RM) erhöht wird, das mit Höchstkraftaufwand in der konzentrischen Phase ausgeführt wird, werden die Daten für die Gestaltung der individuellen Kurven: Kraft-Geschwindigkeit und Schnellkraft-Geschwindigkeit erzielt.

Diese Kurven ermöglichen die Bewertung des Kraftaufwands und der Leistung bei verschiedenen Geschwindigkeiten, womit die Basis für eine sportspezifische Bewertung der Kraftfähigkeiten gebildet wird.

Schlüsselwörter: Muskelkraft, Muskelschnellkraft, Kraft-Geschwindigkeit-Kurve, Schnellkraft-Geschwindigkeit-Kurve, Krafttest

Introduction

In sports, where strength represents a limiting factor of performance, assessment of strength abilities should be an integral part of functional diagnostics. Measurement of strength enables the evaluation of performance potential as well as the efficacy of training.

Traditionally two basic methods, i.e. estimation of one repetition maximum (1RM) or maximal isometric strength have been utilized to assess the strength of particular muscle groups.

1RM reflects the maximal weight, which the subjects tested are able to overcome in the biomechanically most critical position. However, there is no information on velocity or power produced in particular time or position of such a maximal repetition. In addition, such an approach does not provide any information concerning the ability to produce force and power at higher velocities of muscle contraction, i.e. the ability important for the majority of sports performances.

Similar problems are connected with the

measurement of strength under isometric conditions. Information concerning maximal strength at zero velocity and given position does not necessarily correlate with the ability to produce force at higher velocities, i.e. the one required by the majority of sport actions.

Strength at higher velocities can be assessed by means of sophisticated isokinetic systems, which have gained wide popularity in the last two decades. However, they also have their weak points. It is, namely, the artificial character of an isokinetic exercise, which has no relevance to natural sports movements. This kind of exercise also does not allow the assessment of strength abilities in conditions of a real stretch-shortening-cycle, which is considered as another drawback of isokinetic testing machines. Last but not least, high prices of these systems hinder their utilization in practice-oriented evaluation of athletes.

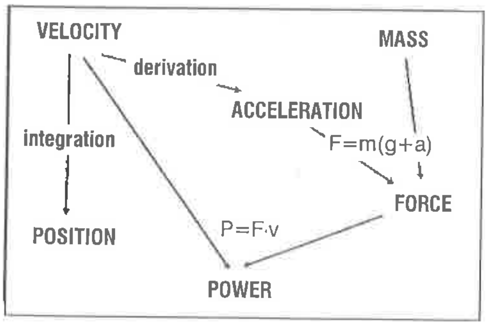
Therefore, there is a need of a method to determine the strength abilities - a method which is not only simple and reliable, but also more sports-specific, i.e. the one which allows the estimation of the ability to produce force and power under high contraction velocities with the involvement of the stretch-shortening-cycle. This paper presents an alternative based on monitoring the basic biomechanical parameters of weight exercise.

Principle and method

Utilizing Newton's laws of mechanics all basic biomechanical parameters involved in weight exercise can be derived from the velocity registered and the weight lifted (Fig. 1).

The force exerted while lifting weight consists of two components, the gravitational and the accelerational one. It can be calculated as a multiplication of mass lifted and the sum of gravitation constant g and instant acceleration. So the actual force may become higher or lower than the gravitational force, depending on acceleration or deceleration of a lifting movement.

Fig 1: Calculation of basic biomechanical parameters of weight exercise from velocity and mass



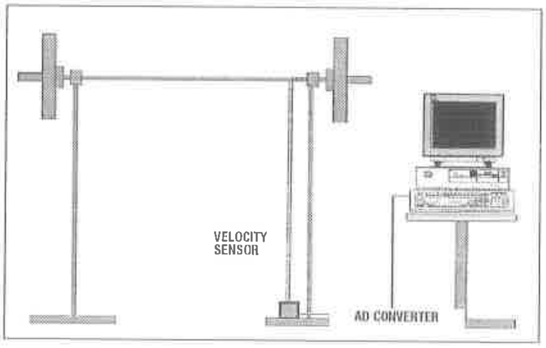
Acceleration can be obtained by derivation of velocity at which mass is lifted in vertical direction. The sum of acceleration and gravitational constant multiplied by mass yields instant force.

Multiplication of force and velocity provides the actual value of power.

By integrating velocity, distance or actual position can be calculated.

By means of a computer the almost instant data in graphic or digital form may be obtained.

Fig 2: Basic scheme of the system for the estimation of biomechanical parameter of weight exercise

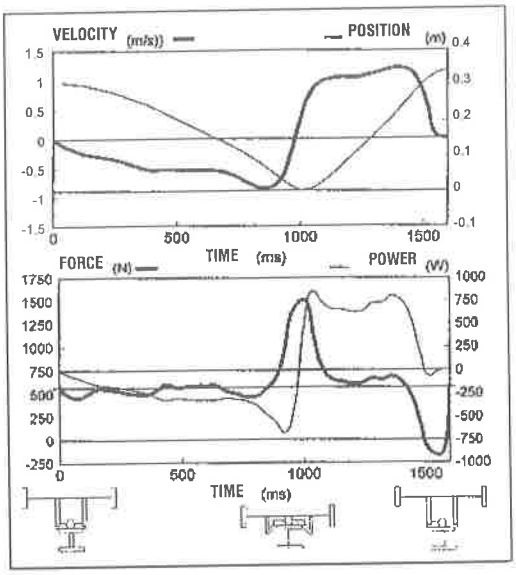


This system (Fig. 2) measures the upward vertical velocity by means of an analog sensor based on the rotating reel tethered to the weight by means of a fine nylon thread. The string mechanism provides the backward movement of the reel.

After AD conversion the signal is conveyed via serial port to an IBM compatible personal computer and processed by a special program.

In this way the system provides all the basic parameters of weight exercise, i.e. force, velocity, power and position in both digital and graphical form. After each repetition the summaries containing maximal and mean values of all parameters are displayed separately for the eccentric and concentric phase.

Fig. 3 depicts an example of data, i.e. force, velocity, power and position as related to time, *Fig 3: Basic biomechanical parameters during a single repetition of a bench press*



collected while performing the bench press with counter movement. In the initial phase of eccentric contraction the force decreases under the gravity value, but after reaching a maximal downward velocity, the force rises in order to decelerate the movement. Maximal force is reached around the turning point, where an eccentric phase changes into a concentric one. High force at the beginning of this phase accelerates the upward movement till maximal velocity is reached. As the force decreases under the gravity value, deceleration sets in resulting in zero velocity in the upper position.

In the eccentric phase there are also the negative values of power. They become positive during the phase of concentric contraction. There is a rather steep increase of its value followed by a sort of plateau despite the fact of rapidly changing the force and velocity. Since power is a product of force and velocity, it remains more or less stable at high force and low velocity (the beginning of the concentric phase), moderate force and velocity (the middle of the concentric phase) and low force but high velocity (around two thirds of the distance between the lower and the upper position).

From the chart it is obvious that the force produced during exercise fluctuates around mean values represented by gravity force of the barbell mass. The amount of this fluctuation depends very much on the way the exercise is being performed.

As seen in Fig. 4, in a dynamic repetition the increase and the decrease of force during the acceleration and deceleration phases are

Fig 4: Basic biomechanical parameters during a bench press performed with a slow and fast movement in the concentric phase

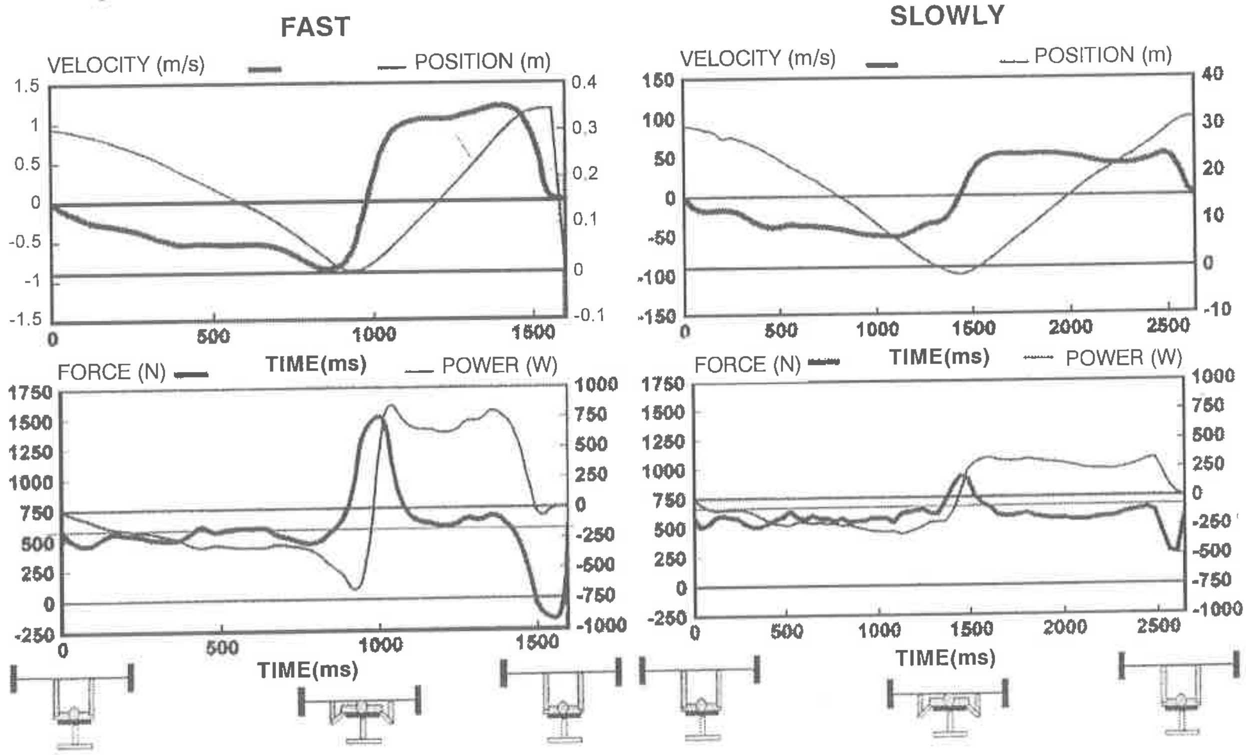
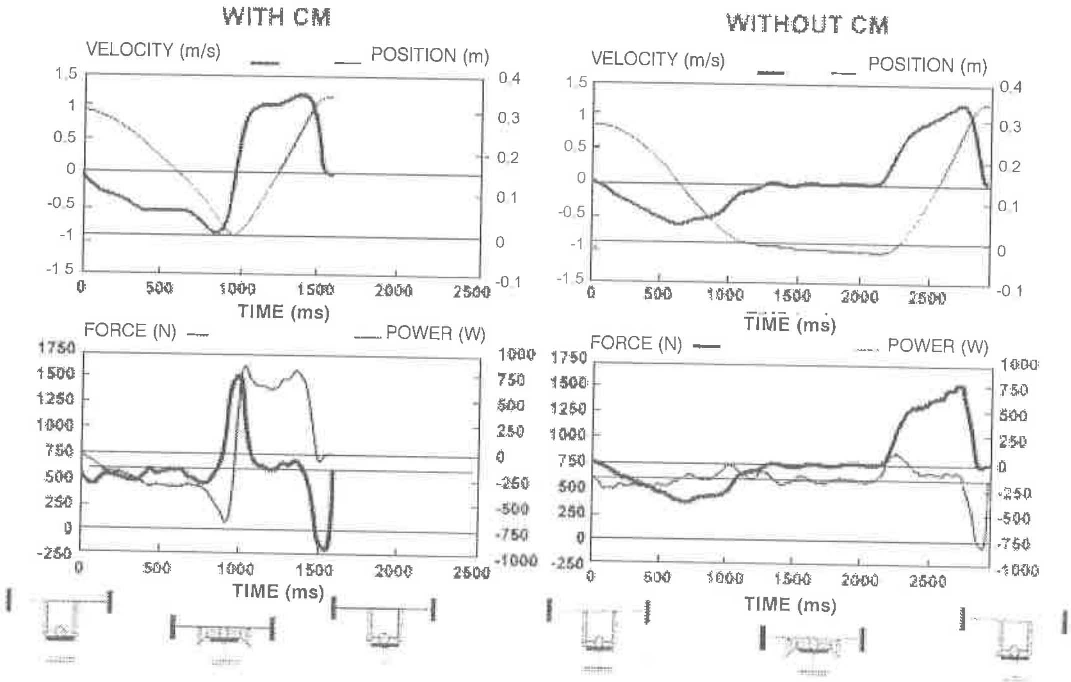


Fig 5: Basic biomechanical parameters during a bench press performed with and without a counter movement



much more pronounced than if the exercise is performed slowly. Accordingly, the peak and the mean values of velocity and power will be substantially higher if the repetition is performed in a dynamic way. One may also expect different recruitment patterns of particular muscle fiber types and consecutively also the different training effects. The way the strength exercise is executed is therefore of great importance for the training practice.

It is also interesting to compare the parameters of repetitions performed with and without a counter movement (Fig. 5). As evident from the figure, counter movement repetition elicits higher velocity, power as well as higher peak force as compared to the repetition with a break in the lowest position. The difference is due to utilization of elastic energy accumulated in the eccentric phase and to activation of stretch-shortening-cycle, which have been shown to potentiate the power production (Komi, 1984).

Because of the higher values of peak force and power in the concentric phase, and also due to the fact that the stretch-shortening-cycle represents an integral part of the majority of natural movement patterns including sport activities, exercises with counter movements should be the preferred strength training modality in athletes.

Fig 6: Mean velocity and power in the concentric phase of bench press repetitions performed with weights from 20 to120 kg

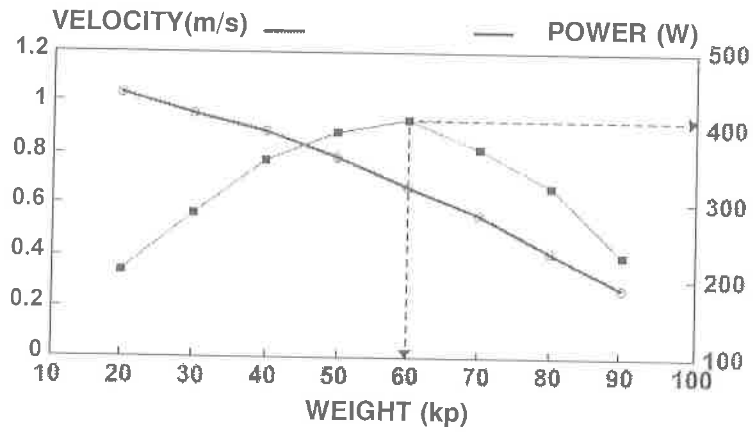
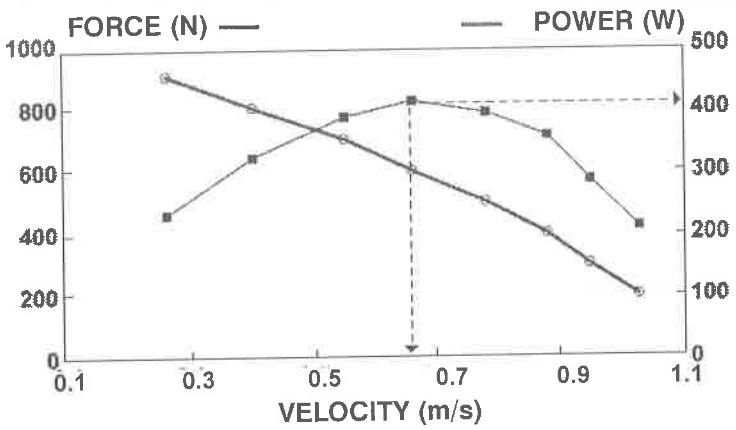


Fig. 7: Force and power in the concentric phase of a bench press produced at different velocities.



Application in the diagnostics of strength abilities

In order to collect the data enabling the assessment of the ability to produce force and power at different velocities, a subject has to perform single repetitions of particular exercise with stepwise increasing weights up to 1RM. The repetitions must be performed with maximal effort in the concentric phase. From the data collected individual curves showing dependence of velocity and power on weight (Fig. 6) and force and power on velocity (Fig. 7) can be constructed.

Fig. 6 contains an individual example of the curves of mean velocity and power, obtained while performing such a diagnostic series of bench press repetitions with weights ranging from 20 to 120 kg.

The increasing of a weight leads to a decrease of velocity. However, power increases from lower weights, reaches a peak around 60 % of 1RM and then decreases again.

The force-velocity and the power-velocity curves show similar behavior based on the same data (Fig. 7). In the majority of subjects maximal power is being produced at velocity close to 50 % of its maximal value.

Curves shown in Fig. 7 allow the assessment of the ability to produce force and power not only at low, but also at higher velocities. This is especially important in sports in which force is to be applied at high velocities. In such a situation muscles, in fact, produce power. Thus, power, incorporating both force and velocity, may be considered as a better parameter of strength abilities than

Fig. 8: Improvement of 1RM and maximal power after 8 weeks of strength training (6x6 repetitions with 70 % of 1RM, 3 times a week) performed with a fast or slow motion in the concentric phase

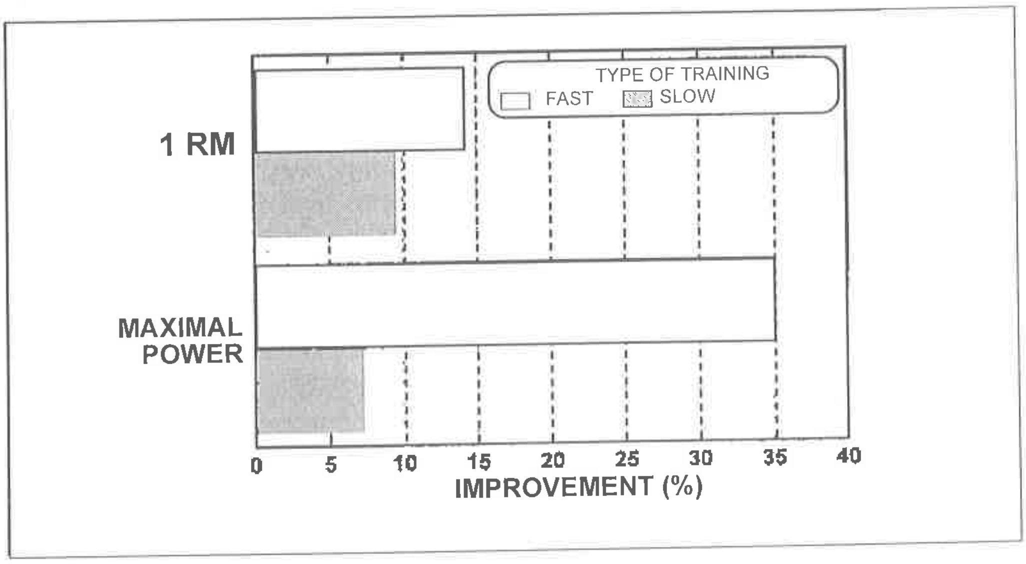
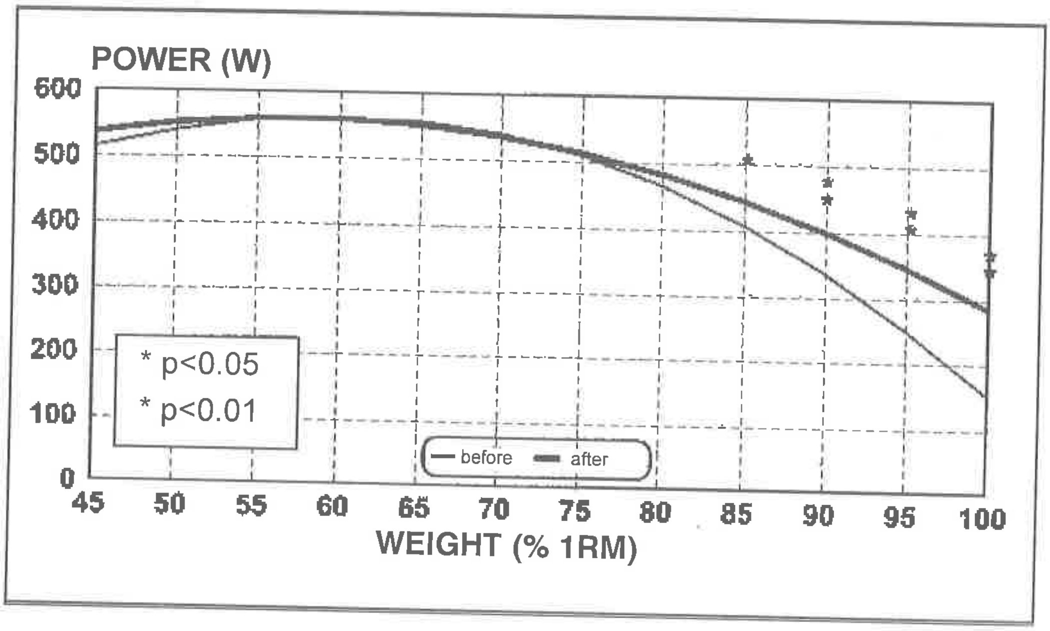


Fig. 9: Change of power after 8 weeks of strength training with heavy weights



1RM itself.

In addition to maximal power, corresponding values of weight and velocity can be obtained, too.

As demonstrated by Tihanyi et al. (1984), optimum velocity, i.e. the one allowing the production of the highest power does depend on the ratio of FT and ST fibers. This also explains why this parameter hardly changes with training, though the increase of optimum weight may be quite substantial.

Some experts recommend the weights at which the maximal power can be obtained to be used in training focused at the improvement of explosive strength. As proved by one of our studies (Gazovic, 1998), if the repetitions with such weights are done with maximal effort, there is a much more pronounced increase of maximal power than 1RM (Fig. 8). This is in fact the change, which is much more important for the performance in the majority of sports. However, lifting the same weights in the same volume slowly yields only a moderate improvement of maximal power.

Fig. 10: Force in the concentric phase of a bench press produced at different velocities in a shot putter and a bodybuilder

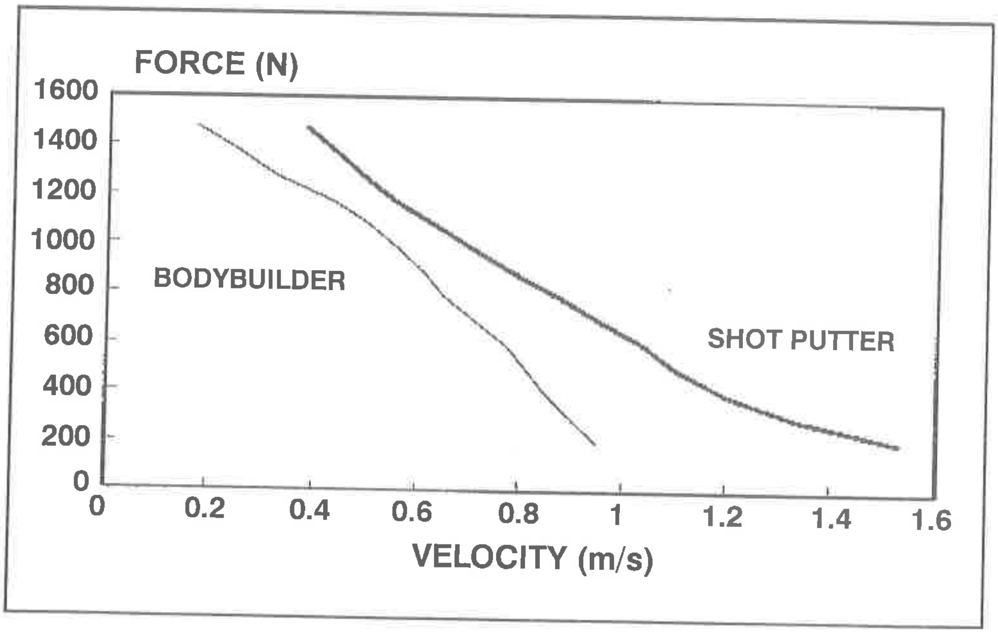
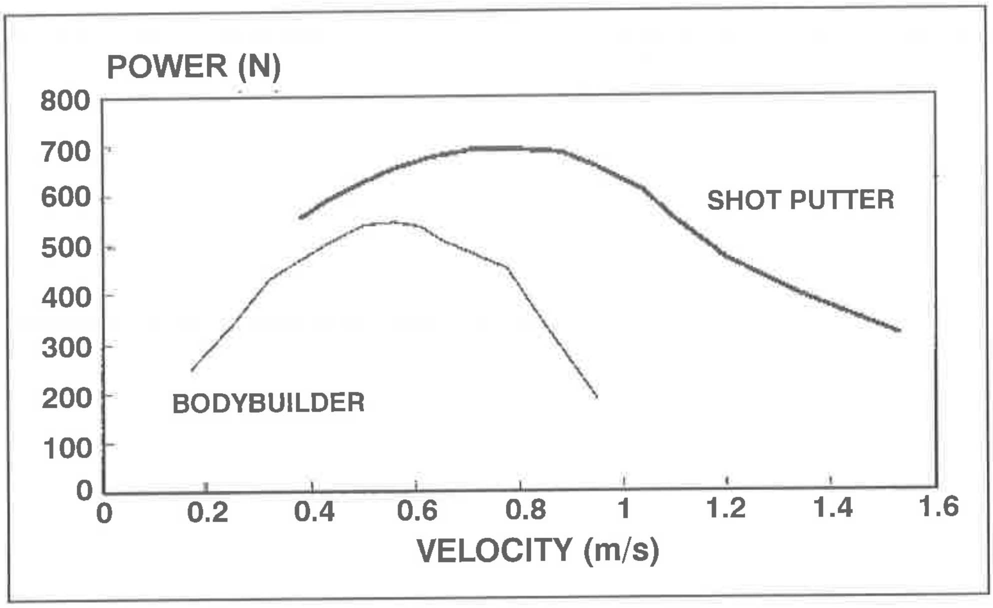


Fig. 11: Power in the concentric phase of a bench press produced at different velocities in a shot putter and a bodybuilder



On the other hand, if training is performed only with weights close to the one's individual maximum, there is an improvement in 1RM as well as power while lifting heavy weights, but there is practically no increase in maximal power (Fig. 9). In the group of top kayak competitors, which were the subjects of this study (Bucek and Hamar, 1997), such a training gain cannot be considered as the most desirable one, since the perfomance in this sport relies on the ability to produce the highest power at a lower resistance but at a higher velocity.

In order to present the diagnostic potential of the system bench press data of two subjects with different training aims, i.e. of a bodybuilder and a shot putter are presented in Fig. 10 and 11.

Though both were able to lift the same maximal weight, the ability to produce force and power, namely at higher velocities, was substantially better in the shot putter than in the bodybuilder. This difference was of shot putters. Though this difference may be partly explained by the genetic endowment, the main reason is very probably the specific effect of strength training at different velocities. It has been reported (Kaneko, 1974, Kaneisha and Miashita, 1983) that training with heavy weights at low velocities, e.g. the one typical for bodybuilders tends to improve the maximal strength and the ability of force and power production at lower velocities, whereas a dynamic training with lower weights enhances the force and power production at higher velocities.

In these cases, using a traditional approach to estimate only 1RM would provide rather misleading information underestimating specific strength capabilities of shot putters, whose performance require the production of power at lower resistance and higher velocities.

Conclusion

It can be concluded that practical experience as well as experimental data indicate that complex monitoring of all biomechanical variables associated with particular strength exercises allows a more precise evaluation of strength qualities as required by particular sports events and a more sensitive assessment of the effects of training aimed at the improvement of explosive power.

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