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## **OPTIMAL VELOCITY TO ACHIEVE MAXIMUM POWER OUTPUT – BENCH PRESS FOR TRAINED FOOTBALLERS**

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### ABSTRACT

In today's world of strength training there are many myths surrounding effective exercising with the least possible negative effect on one's health. In this experiment we focus on the finding of a relationship between maximum output, used load and the velocity with which the exercise is performed. The main objective is to find the optimal speed of the exercise motion which would allow us to reach the maximum mechanic muscle output during a bench press exercise. This information could be beneficial to sporting coaches and recreational sportsmen alike in helping them improve the effectiveness of fast strength training.

Fifteen football players of the FK Třinec football club participated in the experiment. The measurements were made with the use of 3D cinematic and dynamic analysis, both experimental methods. The research subjects participated in a strength test, in which the mechanic muscle output of 0, 10, 30, 50, 70, 90% and one repetition maximum (1RM) was measured. The acquired result values and other required data were modified using Qualisys Track Manager and Visual 3D software (C-motion, Rockville, MD, USA). During the bench press exercise the maximum mechanic muscle output of the set of research subjects was reached at 75% of maximum exercise motion velocity.

**Keywords:** output performance, dynamic motion analysis, cinematic motion analysis, model, bench press, motion velocity

### INTRODUCTION

Maximum muscle output with a given load is the main determinant of performance during physical activities requiring one motion sequence aimed at reaching high velocities during the lift and lowering phases. Neuromuscular activities maximizing output power are necessary in many other exercises such as throwing, jumping and strokes. Apart from the mentioned exercises, sudden increases in output power are needed during sudden changes in

direction or acceleration in different sports and other sporting activities (for example: American football, basketball, football, baseball, gymnastics)” (Kraemer & Newton, 2000).

Same as in other sports the best possible output performance of the upper limb is essential in football. From the point of view of motion coordination, upper limbs play an irreplaceable role, as it is unimaginable for a footballer to undergo a clash with an opponent during a match without the use of upper limbs. The footballer must be able to coordinate his body movements in the shortest possible time. The upper limbs play an important role determining motion velocity. Nowadays it is impossible for a football player to be slow and successful at the same time, therefore the right, effective and dynamic movement of the arms contributes to the overall speed of a player. Modern football coaches thus put emphasis in speed training on exercising the upper limbs and finding the optimal speed for reaching the maximum mechanic muscle output, which would help to increase the effectiveness of training and at the same time increase the performance of player and decrease the risk of injury to the upper limbs.

Hill (1938) was one of the first to search for the optimal velocity of reaching maximal mechanic muscle output and was the first to demonstrate, that the optimal load for reaching maximal mechanic muscle output amounts to 30% of maximum isometric force F<sub>0</sub>. Hill’s measurements were performed on an isolated frog muscle at 0 °C, which may not correspond to the mechanics of a human muscle.

Our main objective is to identify relative motion velocity allowing the set of research subjects to reach the maximum mechanic muscle output during a bench press with counter-movement exercise. The establishing of an optimal velocity and load for reaching maximum mechanic muscle output would contribute to the rationalization of the base load for specific speed trainings (Jandačka, 2008).

## METHODS

### Tested subjects

15 trained football players participated in the experiment at the beginning of the season (summer). Their age, height and weight (average ± st.dev.): 26.1 ± 3.9 years, 183.3 ± 6.7 cm, 78.8 ± 7.2 kg. All tested subjects signed an informed consent form. They were members of the same football club. Other information on the subjects is presented in Table 1.

**Table 1.** Average values of the 15 member football team FK Třinec

Complex	The average age of the test persons	The average age of people tested in the interval	The average of body height	The average of body height in the interval	The average of body weight	The average of body weight in the interval
15 trained football players in the club FK Třinec	26.11 ± 3.87 years	19–33 years	183.3 ± 6.73 cm	1.70–1.96 m	78.8 ± 7.17 kg	65–91 kg

## Test proceeding

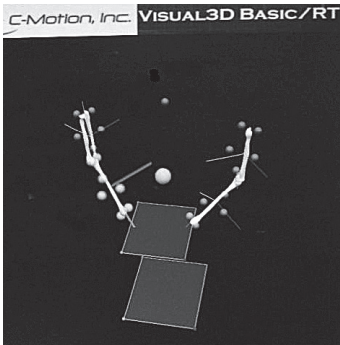
Each tested subject visited the laboratory twice in a one week interval. During the first visit the subjects were instructed in the correct technique of the bench press. The degree of movement of each subject was established in the chest-touch position and was monitored by a sound signal at the lowest and highest points of the movement's trajectory. The Body Segment Composition Analyzer (*TANITA 418 MA, USA*) was used to measure height, overall weight and the weight of individual segments of the upper limb. The first lab visit also included the testing of the maximum output with one repetition according to the protocol published by Kraemer, Ratamess, Fry and French (2006).

The second visit to the laboratory by the research subjects included the measuring of output during the bench press exercise with the base load being gradually increased from 0, 10, 30, 50, 70 to 90% with one repetition. Reflexive markers were placed on a subject's *acromion, medial epicondyle of humerus, lateral epicondyle of humerus, radial styloid process* and on the *lateral and central sections of the barbell*. Also, 4 light durable plates each carrying three markers were placed on the upper upper limb segment and the forearm.

As soon as the tested subject assumed the starting position on the bench with no load, the output power measuring platforms were calibrated to zero. The footballers assumed a bench press lifting position with their feet being placed on a footrest attached to the bench and chose individual grips of the barbell that they regularly use during the exercise. After capturing a static record, in which the subjects were asked to stand in a starting upper position with the barbell and three acceptable lifting attempts were recorded with each load. An accepted attempt is such an attempt in which the subject kept his movements in the specified range during the lift. The subjects were instructed to lower the barbell in a controlled fashion until they reach the lowest position. Once this position was reached a sound signal went off (*equipment FitroDyne Premium, Fitro, Slovakia*) and the subject was asked to perform a lift with maximum velocity. The subjects were also instructed not to raise their torso from the bench or toss up the barbell. A three minute rest period was set in between lifts. Three lift attempts were recorded for each load. Average values of the three attempts were used for further analysis.

## Experimental settings

Two output power measuring platforms (*Kistler 9281CA and 9286AA, Switzerland*) built into the floor beneath the bench taking in data with a frequency of 988Hz were used to measure the contracting forces between the bench and the pad during the lift. 3D upper limb motion data was taken by a seven camera motion recording system (*Qualisys Oqus, Sweden*) with a recording frequency of 247 Hz during the bench press exercise. A linear position converter (*FitroDyne Premium, Slovakia*) emitted sound signals which were heard by the subjects. The sound signal changed when downward motion changed into upward motion. The testing exercise was performed with a loose barbell without the use of bearing rails.



**Figure 1.** Representation of the model's processing in Visual 3D software (C-motion, Rockville, MD, USA). Note: The figure was taken at the Center for human motion diagnostics in Ostrava.

## Data analysis

Output (**W**) was calculated as the multiple of the vertical force (**N**) and the vertical velocity (**m/s**) of the centre of gravity (center of gravity of the upper limbs segments and the barbell). The center of gravity's velocity was a necessary parameter which was calculated by the V3D software. The data acquired with the help of reflexive markers was processed by the Visual SD software (*C-motion, Rockville, MD, USA*). The processed data is shown in Table 1. All upper limb segments except for the palms were modeled as truncated cones, the barbell was modeled as a cylinder. Vertical force (**N**) was established as the sum of two signals from two force measuring platforms recording vertical forces applied on the pad (**N**) and the weight of upper limbs (**N**). The upper limb weight (**N**) was calculated as the multiple of the upper limbs mass (**kg**) and gravitational acceleration. Output power (**N**) was determined for each lift with each load. We analyzed the segment of a movement which demonstrated positive output (**W**).

By determining the velocity (**m/s**) of the center of gravity an acceleration and deceleration phase of upward movement (lift) was established. In this manner the average output for each lift with each load (**% 1RM**) during positive output motion and the acceleration phase was determined. The maximum output (**W**) was the absolute maximum for all loads.

## STATISTICAL ANALYSIS

The output (**W**) to maximum output (**W max**) ration was established for each subject with each load (**kg**). The resulting average values for each load and velocity were used to create a multi-linear regression model, which describes the quadratic relationship between the output to maximum output ratio and the load to velocity ratio for two data sets.

This regression model (in Figure 2) was created in accordance with the least squares method using Matlab software. The created model may be expressed by this formula:

$$\frac{P}{P_{mm}} = b_1 \left( \frac{L}{1RM} \right)^2 + b_2 \left( \frac{v}{v_{mm}} \right)^2 + b_3 \left( \frac{L}{1RM} \right) \cdot \left( \frac{v}{v_{mm}} \right) + b_4 \left( \frac{L}{1RM} \right) + b_5 \left( \frac{v}{v_{mm}} \right) + c$$

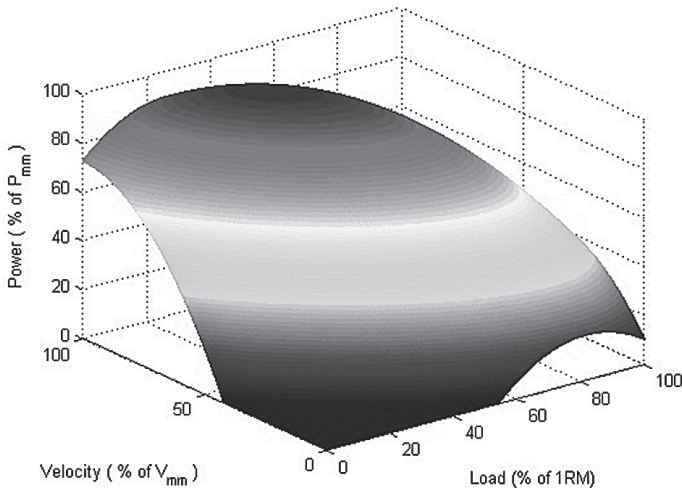
**Figure 2.** The regression model (Hori et al., 2007)

$P_{mm}$  being the average maximum output (**W**),  $P$  the average output (**W**),  $1RM$  is the maximum load (**kg**),  $L$  is the load (**kg**),  $v_{mm}$  is the average maximum velocity (**m/s**),  $v$  is the average velocity (**m/s**),  $b_1$ ,  $b_2$ ,  $b_3$ ,  $b_4$  and  $b_5$  are regression coefficients and  $c$  is the regression constant. The validity of the two constructed linear regression models was established (Hori et al., 2007).

We used the Statgraphics Plus software to verify the key assumptions, which must be valid. The optimal load and the velocity of the regression model was established by the trust region method in combination with the Quasi-Newton method. We used the Levenberg-Marquardt implementation of the trust region method in the Matlab computer program. At the end we utilized the Statgraphic Plus software to calculate the **95% confidence interval**.

## RESULTS

The determination coefficient for the creation of the regression model is **0.7353**. The created regression model may be seen in Figure 3. In the visual representation of the model we may see a color 3D pattern depicting the relative relation between the output (%  $P_{mm}$ ), velocity (%  $v_{mm}$ ) and the load (%  $1RM$ ).

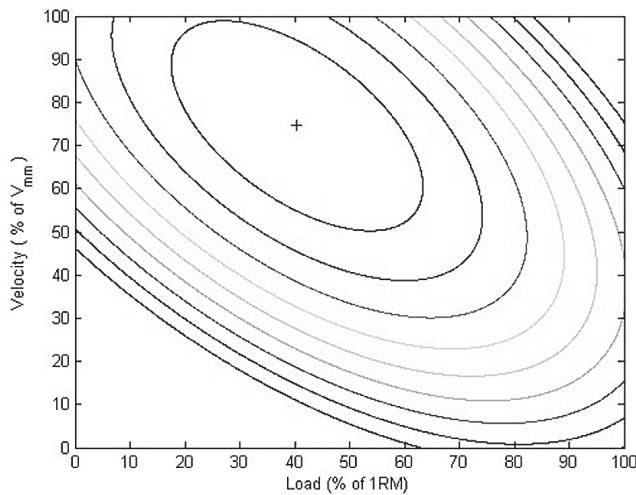


**Figure 3.** Regression model describing the relation between relative output (%  $P_{mm}$ ), velocity (%  $v_{mm}$ ), load (%  $1RM$ ) (experimental data by author)

The resulting model is depicted from the side (slightly turned to the left) to allow us to see all axes. The **X axis** depicts the velocity of the explosive force of the performed bench press exercise expressed in percentage  $v_{mm}$ , which was the main objective of our research experiment. The optimal mass for attaining the maximum mechanical muscle output expressed in %  $1RM$  is depicted on the **Y axis**. Prior research (Billich, 2010) shows, that the maximum mechanic power output of a set of tested subjects was attained with a relative percentage mass load of 52%  $1RM$ . This load figure could be the optimal load for non-ballistic training, during which the maximum power output during the shortest possible period of time should be achieved. The maximal mechanic muscle output expressed in % is depicted on the **Z axis**. The result may be observed in the color combination of stacked up layers, from which we can ascertain the optimal velocity for attaining the maximum mechanic muscle output which accounts to **74.5779%**  $v_{mm}$  by lowering a perpendicular from the center of the red field onto the X axis. The optimal velocity is dependent on the use of the optimal load (%  $1RM$ ) and output (%  $P_{mm}$ ).

Figure 4 depicts the contour of the regression model which represents the result in 2D representation when looked at from above. This contour is composed of two axes. The **X axis** representing the optimal load for attaining maximum mechanic muscle output expressed in %  $1RM$ , is dependent on the previous measurement of  $1RM$ , which is unique for each individual. The **Y axis** depicts the optimal velocity of the burst force of each bench press expressed in %  $v_{mm}$ . The resulting relation of these two quantities is represented by the red cross. This cross shows us that the maximum mechanic output which is attained when the value of the burst force velocity during a bench press exercise is **74.5779%**  $v_{mm}$  depending on the optimal load which is set at around 40%  $1RM$ .

The resulting optimal value of the velocity at which maximum mechanical muscle output is reached is **74.5779%**  $v_{mm}$ .



**Figure 4.** Regression model contour, which represents the relation between the relative output (%  $P_{mm}$ ), velocity (%  $v_{mm}$ ) and load (%  $1RM$ ). The cross represents the point of the maximum mechanic output (experimental data by author).

## DISCUSSION

The aim of this paper was to determine the optimal velocity for attaining the maximum mechanic muscle output during bench press performed by trained football players.

First we created a regression model describing the mutual relation between output, maximum dynamic force, maximum velocity, load, maximum output. The model corresponds with the acquired data. The value of the determination coefficient between the measured data and the model is 0.74 for the acceleration phase and 0.75 for the whole positive output period. This confirms that the regression model corresponds to the measured data. The model establishes the dependence of the output on the external load and incorporates data on motion velocity of a given exercise. It can be used not only for the determining of the optimal load for attaining the maximum output but also for determining any of the included parameters: load, output, velocity, maximum output, maximum velocity or the one repetition maximum.

From Hill's equation we were able to deduce that the maximum mechanic muscle output is attained by about a one third of the maximum force and maximum instant velocity (Hill, 1938). Our model projects that for the acceleration phase of the bench press lift with a 1RM load the optimal average velocity is 74.58% (lower boundary of the confidence interval being 70.32% and the upper boundary being 87.14%)  $v_{mm}$ . The optimal average velocity of motion established in our study significantly differs from the optimal 30% of the peak of the maximum velocity laid down by Hill. When approximating the optimal load and velocity needed to reach the maximum muscle output during the positive output phase of the bench press lift our model assumes the optimal velocity at 74.58%  $v_{mm}$  (with the lower boundary of the confidence interval being 65.62% and the upper boundary being 98.15%).

## CONCLUSION

The optimal velocity for attaining maximum output in a set of trained football players with similar strength capacity was set at 75%  $v_{mm}$ . From the acquired data we were able to construct a regression model, which allowed us to calculate the optimal velocity of a bench press exercise. There is a number of myths among professional football coaches established in the past which unfortunately still influence the fashion in which they conduct training. The result is the low effectiveness of training exercises. Therefore we decided to focus our study on the widely used bench press exercise and its optimal lift velocity. The lack of knowledge of the optimal velocity in many cases leads to ineffective training sessions from the point of few of the power output but also increases health risks which can lead to injury such as biceps and triceps ruptures.

For trained football players with a similar strength capacity, this study set the optimal velocity for attaining maximum output at **74.5779%**  $v_{mm}$ . Instructing an exercising subject on the percentage of the maximum velocity he should comply with is in practice impossible. **74.5779%** of the maximum velocity cannot be determined without the use of special measuring equipment, such as Fitrodyne premium. Before beginning a bench press exercise it is necessary to measure the maximum lift velocity. This value



can subsequently be used to calculate the optimal velocity. For example the maximum velocity of a lift conducted by a football player with a load of 50 kg is 100m/s, the optimal velocity is therefore **74.5779 m/s**. The training session must be under the constant supervision of the couch, who can with the help of Fitrodyne Premium guide the subject on the optimal velocity which will improve the effectiveness of the exercise. The subject benefits by exercising in an effective and health-risk-free fashion. The set optimal velocity prevents overloads and at the same time guarantees effective muscle strength training.

## LIST OF SYMBOLS

BP	The pressure of the touch lying on bench (Bench Press)
E	Energy
F	Strenght (N)
$F_{mm}$	Maximum achieved strength
$F_0$	Maximal isometric (static) strength (N)
FR	Reaction force (N)
$m_{opt}$	Optimal weight load (kg)
MDS	Maximum dynamic force
P	Power (W)
$P_m$	Maximum mechanical muscle performance achieved when the size parameters of motor task does not change (W)
$P_{mm}$	Maximum mechanical muscle performance achieved when the size parameters of the motor task systematically changing (W)
$P_{max}$	Maximum power (W)
RM	Repetition maximum (kg)
r	The correlation coefficient
s	Track (m)
sd	The standard deviation
t	Time (s)
TO	The test subject
v	Velocity (m/s)
$v_{mm}$	The maximum speed achieved when the size parameters of motor task systematically changing (W)
$v_{opt}$	Optimal speed (m/s)
1RM	One-repetition maximum (kg)

## ACKNOWLEDGEMENT

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### **OPTIMÁLNÍ RYCHLOST POHYBU PRO DOSAŽENÍ MAXIMA VÝSTUPNÍHO VÝKONU – BENCH PRESS U TRÉNOVANÝCH FOTBALISTŮ**

RICHARD BILLICH, JAKUB ŠTVRTŇA, KAREL JELEN

#### SOUHRN

Dnešní svět silového tréninku přináší řadu mýtů o tom, jak cvičit efektivně a zároveň s co nejmenším negativním vlivem na zdraví člověka. V tomto experimentu se zabýváme nalezením vztahu mezi maximálním výkonem, použitou zátěží a rychlostí. Hlavním úkolem je nalezení optimální rychlosti pohybu pro dosažení maximálního mechanického svalového výkonu při cvičení bench press, což pomůže nejenom trenérům, ale i rekreačním sportovcům zefektivnit trénink rychlé síly. Tohoto výzkumu se zúčastnilo 15 fotbalistů týmu FK Trinec. Měření probíhalo za použití 3D kinematické a dynamické analýzy pohybu experimentální metody. Zkoumaná skupina se zúčastnila silového testu, u kterého byl měřen mechanický svalový výkon s 0, 10, 30, 50, 70, 90 % a jednoho opakovacího maxima (1RM). Získané hodnoty výsledků a potřebné údaje byly následně upravovány v programech Qualisys Track Manager a Visual 3D software (C-motion, Rockville, MD, USA). Při cvičení bench press bylo maximálního mechanického svalového výkonu dosahováno u výzkumného souboru při rychlosti cvičení 75 % maximální rychlosti.

**Klíčová slova:** výstupní výkon, dynamická analýza pohybu, kinematická analýza pohybu, model, bench press, rychlost pohybu

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