© Editorial Committee of Journal of Human Kinetics

Sledge as a Useful Method for Assessing Muscle Performance (Apparatus and Methodology)

by
František Vaverka[1], *Petr Stromšík, Milan Elfmark, Jakub Krejcí*

The method of assessment of quality of muscle performance of the lower extremities while producing the take-off called sledge is presented in this study. The system enables to perform the measurement of actions of lower extremities one repetition or repeated different variations of the take-off. The apparatus consists of a mechanical, controlling and assessing part which is controlled by special software. The mechanical part is composed of rails with the possibility to adapt the slope within the range of 0° to 45°, the sliding cart with an inbuilt chair allowing individual adaptation of the trunk position and two kinds of sensors (dynamometry platform and measurement of the trajectory of the cart). The rail slope permits to adapt the load on the tested subject from the magnitude lower than his/her mass to the load exceeding it. The assessment of the quality of the take-off is based on the analyses of the reaction force measured on the force platform (this procedure is demonstrated in this paper) or based on the analyses of the measured trajectory of the moving cart. A total of 28 measured and computed variables describes in detail the time and force course of the movement, the velocity of the movement and track of the cart, work and power. The system can be used as a very precise tool for solving of a high spectrum of scientific problems, training management or as a training device for the improvement of the take-off.
Keywords: *sledge, take-off, apparatus, measurement, analysis*

[1] Department of Biomechanics and Engineering Cybernetics, Faculty of Physical Culture, Palacký University, tr. Míru 115, 771 11 Olomouc, Czech Republic, vaverka@ftknw.upol.cz

Introduction

A number of sports require physical activity over a prolonged period of time and the end result of such sporting activities are anaerobic in nature (take-offs in volleyball and basketball, starts and stops in tennis, etc.). From a theoretical perspective of physical abilities we refer to such processes as explosive actions requiring the production of maximal strength over a short time interval. From the point of view of sports training and the preparation of an athlete for a given activity, it is essential to obtain information on the quality of muscle strength and power output relevant to the duration of the activity. For this purpose, a wide range of diagnostic procedures are used – tests that provide qualitatively as well as quantitatively different level of information on muscle strength. A specific problem includes the diagnosis of anaerobic endurance as a meaningful factor of efficiency in all arrays of sports. This paper presents the SLEDGE method as a very suitable tool for solving the above-mentioned problem, for elaborating the methodology of the procedure and for verifying the test.

Problem

An extensive data on the quality and extent of muscle contraction exists. The following text does not attempt to address the functional capacity of muscle efficiency (it is rather of fundamental interest in physiology). It is focused only on the motor and biomechanical aspects. There are several possibilities for obtaining information on muscle strength. The simplest method includes repeated tasks in sports where the force capacity is manifested in the natural state of movement performance and the quality criterion is the achieved result (for instance repeated sprints over a short distance, series of jumps, etc.). To this group we can also include measurements on specific trainings devices more or less simulating selected physical movements. The amount of information concerning force demonstration during work on a training device depends largely on the evaluation principles of movement and the technical level of the apparatus (kinematic and kinetic analyses). The mentioned apparatuses are strictly single-purpose and for generally oriented diagnosis they are of little use. The simplest possibility of assessing anaerobic performance is the application of motor tests, such as vertical jump, standing long jump, etc., as a test of explosive force of the lower extremities (Mekota and Blahuš 1983). The quality of information regarding the level of explosive force depends on the technical solution of scanning the vertical jump when obtained information moves from basal level (measured height of jump) to a stage of considerable amount of information using the dynamometric platform (kinematic and kinetic analyses, Brügemann 1994; Vaverka 2000). A great number of papers rely on the vertical jump as a suitable model for solving a multitude of research problems. A limitation for vertical jump for the purpose of detecting anaerobic endurance is the demand on movement solution during repeated jumps (standardisation of movement is influenced by the size of dynamometric platform) and increased load that does not enable the application of a larger series of jumps. Direct information on the quality of muscle strength renders its direct measurement with the support of different systems (for instance CYBEX, BIODEX and others). Contemporary sophisticated systems enable measurement of muscle strength in different modes of muscle contraction (isometric, concentric, eccentric) and during different speeds of contraction (defining angular speed). The mentioned systems provide very precise and useful information on the muscle strength with, however, the following limitations: information is restricted only to one measured muscle group and one measured mode of muscle contraction.

In reality, muscle activity seldom involves pure forms of isolated isometric, concentric or eccentric actions. In many sport tasks muscles work eccentrically with immediate concentric action following. The muscle is active both in the eccentric and concentric phases and this combination of ECC-CON muscle contraction is called the stretch-shortening cycle (SSC) (Norman and Komi 1979). The purpose of SSC is to make the final action more powerful than that resulting from the concentric action alone. The theory of SSC was elaborated by Komi (1992) after considerable basic research during the preceding period (Bosco *et al.* 1982; Komi 1984; Aura and Komi 1986a, 1986b; Gollhofer *et al.* 1987a, 1987b). Nicol *et al.* (1991a) solved the problem in the field of anaerobic endurance. The key to solving the above-mentioned problem was the development of a new methodology called the sledge (Aura and Komi 1986b). The new system combines the advantages of diagnosing complex extensive movements of lower extremities with high standardisation of the examined movement and laboratory precision of assessment. Currently, approximately 15-20 similar systems exist in different laboratories around the world including the biomechanical lab at AWF Warsaw. Authors opted to develop a methodology focused on diagnosing the take-off activity of the lower extremities by means of the sledge apparatus and to familiarise the scientific community with some aspects of this issue.

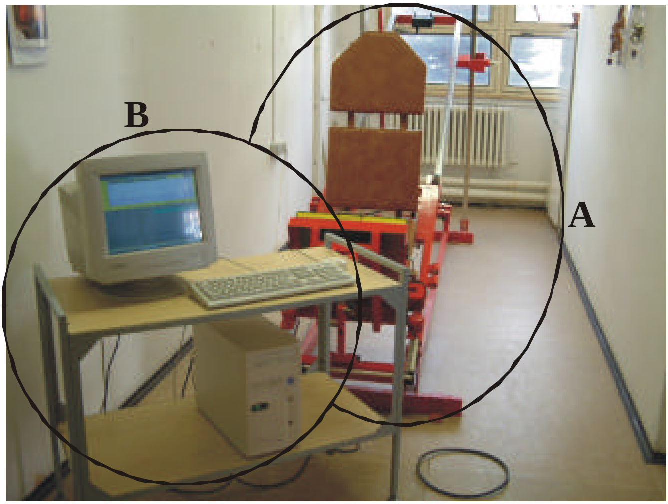

Fig. 1

System SLEDGE

The presented study addresses the basic description of the apparatus, formulation of a mathematic model of a moving subject, algorithm and presentation of assessing the take-off, problems of friction, presentation of methodology of measurement and assessing the variables and verification of stability and validity of the individual take-offs. In the second study we will deal with the problems of friction, determination of the centre of gravity in the system, verification of stability and validity of the test regarding individual take-offs.

Sledge – mechanical and scanning part

The “SLEDGE” apparatus consists of two basic parts (Fig. 1):

A – the mechanical part with scanning components

B – the controlling and assessing part (PC and specialised software)

A) The mechanical part with scanning components consists of the following components (Fig. 2):

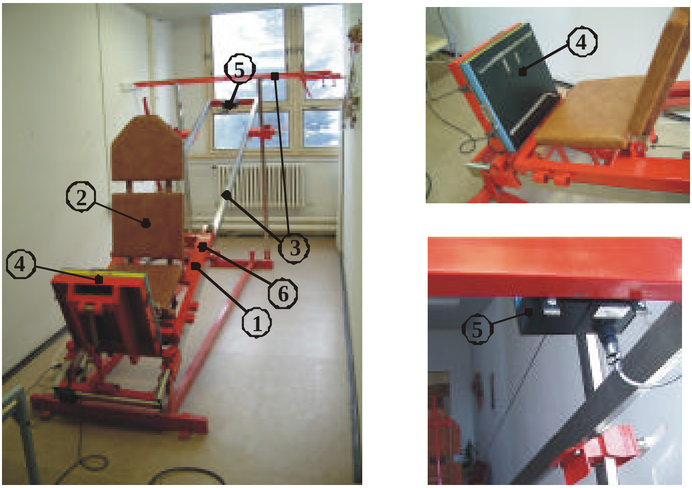

Fig. 2

Mechanical part of the sledge and sensors
1) Sliding cart – the sledge that moves on two rails on which sits an adaptable chair for the examined subject. The chair allows stabilisation of trunk position and the upper extremities in the selected position and allows free movement of the lower extremities from maximal flexion up to total extension during the realisation of take-offs. 2) The chair allowing individual adaptation of trunk position. 3)Two rails (cross section profile about 5x8 cm) on which the cart moves. The inclination of the rails is freely changeable from 0° to 45° allowing only slight change in the load for the examined subject to overcome during take-off. 4) Dynamometric platform allowing scanning the reaction forces in the vertical direction. 5) Measuring apparatus connected with a thin string to the sliding cart recording the shift trajectory of the sliding platform (cable-extension position transducer PT5A). 6) A built-in sliding cart scanner measuring trajectory changes of its shift (own construction). B) Controlling and assessing system comprising a PC and specialised software.

Tested movement activity

The sledge is a preferred method in the diagnosis of complex extension movement of the lower extremities from the point of view of take-off activities, performed under specific conditions, enabling very slight differentiation in overcoming the load. The tested person overcomes the load depending on his/her body weight, the weight of sliding cart and the inclination of the cart trajectory (angle a). It means that it is possible to simulate take-offs not only with load less than the weight of the examined subject (small angles of rail inclination) but also where it is higher than his/her given weight (larger angle of rail inclination and additional load on the cart). The great variability of the overcoming load greatly extends the scope of research possibilities of this diagnostic device. Fundamental movement variations during testing on the sledge can be divided into two groups. These include individual take-offs in different modifications and partly repeated take-offs.

Individual take-offs can be tested in two classical variations. One of them is a performance from an initial position of bent lower extremities (character of muscle contraction isometric-concentric contraction - squat-jump). Record of reaction force during this variation is shown in Fig. 3A).

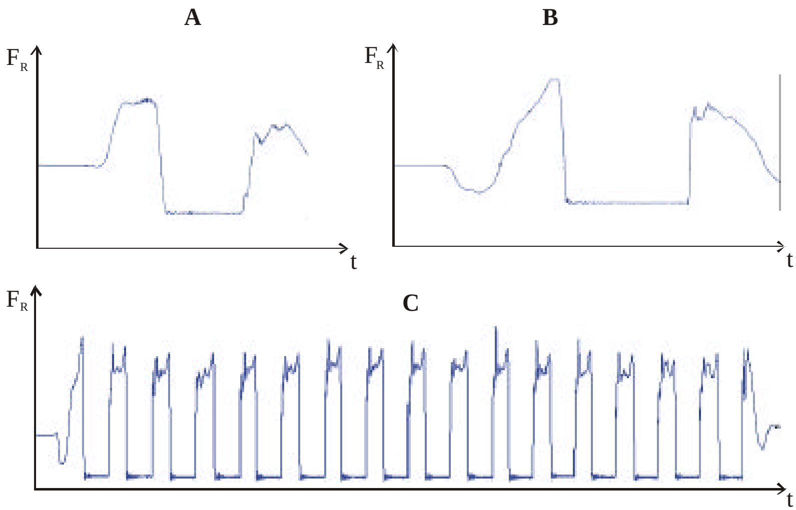

Fig. 3

The force-time curve FR(t) of the reaction force measured on the force plate A – squat take-off, B – counter-movement take-off, C – continual repeated take-off

The second variation (Fig. 4), the most often used, is the take-off starting with stretched lower extremities by bending (lowering – countermovement) so that the tested subject gets into the starting position from where he/she realises the take-off (character of muscle contraction is eccentric-concentric - counter-movement jump). Record of reaction force during this variation of take-off is shown in Fig. 3B). One of the many diagnostic possibilities of anaerobic activity during jumps from starting position is to repeat individual take-offs in different time intervals. Here, a very interesting possibility exists to test repeated take-offs under highly standardised and controlled conditions (character of muscle contraction is eccentric-concentric). Record of reaction force during this variation of jump is shown in Fig. 3C). The apparatus allows to diagnose force production during repeated take-offs as well as anaerobic endurance.

Fig. 4

Counter-movement take-off

Model of algorithm development of the task

It is possible to conduct an analysis of movement activity on the sledge on the basis of two variations of the scanned data. This is data obtained from a dynamometric platform $F_R(t)$ (dependency of reaction force of take-off on time) or data obtained through measurement of trajectory of the sliding cart s(t).

Fundamental algorithms of analysis of measured reaction force $F_R(t)$ during take-off on a sledge are in principle congruent with the analysis of reaction force during the vertical jump on a dynamometric platform (Vaverka *et al.* 1979, 1980, 2000). A scheme of acting forces during tests of the take-off on the sledge is shown in Fig. 5.

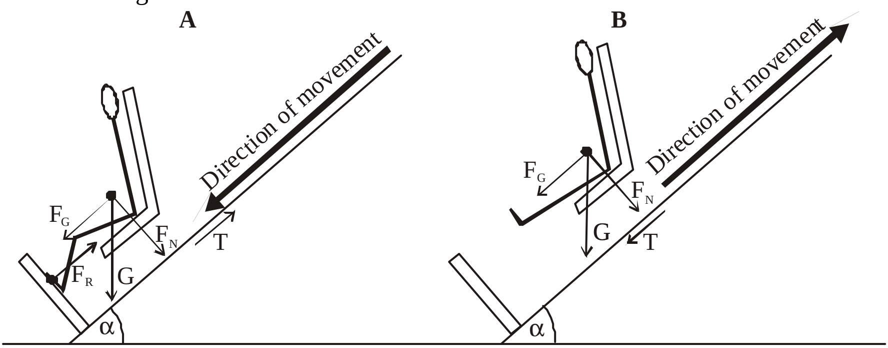

Fig. 5

Basic scheme of forces acting in the sledge test G – gravitational force; FG – component of the G parallel to the slope of rails, FN – component of the G perpendicular to the slope of rails, FR – reaction force of the take-off, T – friction; a – slope of the rails

From the point of view of system of acting forces it is necessary to differentiate two movement phases. The phase of examined person's contact with measuring platform (support phase) when non-zero reaction force takes origin $F_R(t)$ and the phase of platform move after take-off (non-support phase) when $F_R(t) = 0$. General algorithm of calculation of trajectory s(t) and the speed V(t) of a moving subject and the cart is as follows:

$$S(t) = \frac{1}{m}\int_{t_0}^{t} v(t)dt = \frac{1}{m}\int_{t_0}^{t}\left(\int_{t_0}^{t} F_R(t)dt\right)dt$$

where $F_R(t)$ is the reaction force dependent on take-off force of examined subject and component of gravity force F_G coplanar with rails inclination. Weight (m) is given by summation of the subject's weight and the cart, V(t) is movement speed, s(t) is the trajectory of movement of the system examined subject – cart. Analysis of take-off is realised in time interval (t_0 , t_i) providing that the initial values s(t) = 0 a V(t)= 0. Modified component of gravity force F_G depends on the total weight of examined person and cart m, the rails inclination angle α and coefficient of friction μ. Value of F_G is calculated from the relation of $F_G = G(\sin\alpha - \mu\cos\alpha)$. Orientation of acting forces $F_R(t)$ and F_G is always the same. Only the friction force T changes orientation according to the direction of cart movement. During cart movement towards the dynamometric platform (Fig. 5A) T decreases the size of F_G and on the contrary during the cart movement nose-up (Fig. 5B) T increases the size of F_G. The size of friction depends on the quality of technical solution of cart movement on the rails and the general effort here is to minimise this force so that it influences the size of F_G as least as possible. By analysing the measured function $F_R(t)$ and the calculated functions V(t) and s(t) we obtain an array of exact information pertaining to the performance of take-off. The result of analysis of individual take-off during variations of counter-movement jump is shown as a graph in Fig. 6 and the characteristics of measured variables is presented in Table 1.

Performance of take-off in the regime of counter-movement jump is structured into 6 movement phases. The preparatory phase commences from the moment of stretched lower extremities by bending the limbs of subject to initiate the downward movement. The braking phase is an important part of the take-off during which the movement downwards is delayed. Muscle groups that realise the take-off are stretched (eccentric muscle contraction) and muscle force increases.

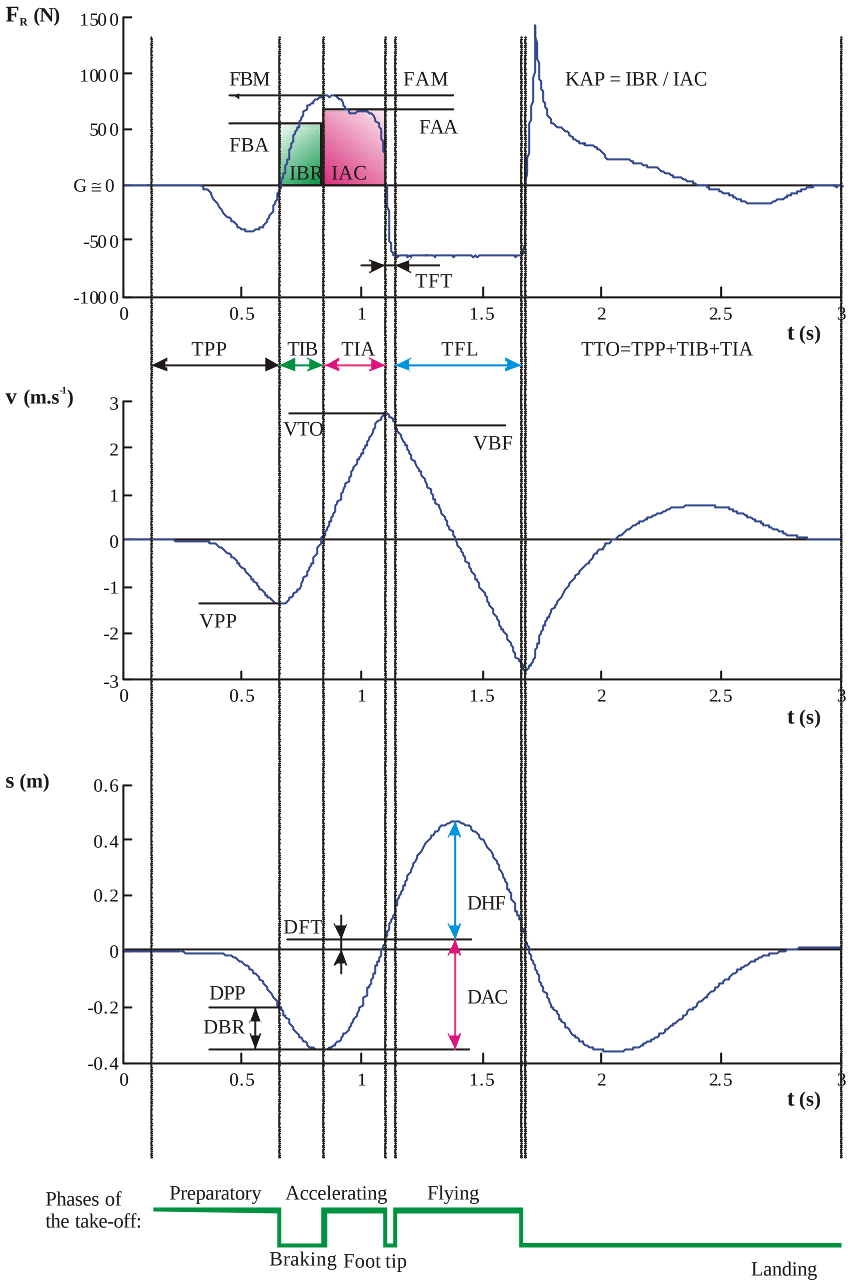

Fig. 6

Kinetic analysis of the take-off on the sledge. Graphical expression of measured variables

Table 1

Kinetic analysis of the counter-movement and squat take-off on the sledge. Measured variables

Group of variables	Variable	Description
Time (s)	TPP	time of preparatory phase
	TIB	time of braking impulse phase
	TIA	time of accelerating impulse phase
	TFT	time of fall of reaction force F(t) = F_G on the level F(t)=0
	TFL	time of the flight phase
	TBA	time of braking and acceleration phase; TBA=TIB+TIA
	TTO	total time of take-off (contact with the force plate); TTO=TPP+TIB+TIA
Force (N)	FBM	maximal force in the braking phase
	FBA	average force in the braking phase
	FAM	maximal force in the accelerating phase
	FAA	average force in the accelerating phase
	IBR	force impulse in the braking phase
	IAC	force impulse in the accelerating phase
Velocity ($m.s^{-1}$)	VPP	maximal velocity in the preparatory phase
	VTO	velocity of the take-off
	VBF	velocity in the beginning of the flight phase
Distance (m)	DPP	distance of the lowering of the CG in the preparatory phase
	DBR	distance of the lowering of the CG in the braking phase
	DAC	distance of the raising (elevating) of the CG in the accelerating phase
	DLM	distance of maximal lowering of the CG; DLM=DPP+DBR
	DFT	distance of the foot-tip
	DHF	distance of the take-off height
	DHI	distance of the height of jump computed from IAC
Work (J)	WBR	work in the braking phase
	WAC	work in the accelerating phase
Power (W)	PAV	average power
	PMX	maximal power
Computed	KAP	Ratio IBP and IAC; KAP=IBP/IAC

The acceleration phase (concentric work) determines the resultant force impulse and total take-off result. The phase of foot tip is a short-time moment when the size of reaction force $F_R(t)$ from level of F_G declines to zero. The size of TFT is very small (TFT=0.022 ± 0.008 sec.) but its meaning lies in the possibility to calculate the distance of take-off from full foot contact with dynamometric platform until the moment when toes leave the platform. Other phase is the flight phase when the examined person is not in contact with force plate and moves according to the principles of free fall upwards. The last phase is the landing commencing during re-contact of the examined subject with the force plate and ends in the resting condition. The phase of landing is not included in the elaborated software. By the mentioned procedure it is possible from single take-off to obtain an array of precisely measured information on the time, force, velocity and trajectory of movement, work and power. In this case the elaborated software provides 28 variables describing single take-off of the counter-movement jump (Fig. 3B). The mentioned procedure may be used for analysing the reaction force during the take-off called the squat-jump (Fig. 3A). In this case variables characterised by preparatory phase of movement and countermovement before the take-off will not be included in the final analysis. The indicated methodology allows solving a great spectrum of research and training problems in the field of take-off activity. The elaborated software allows developing a diagnostic system, can be used for research, as well as development of lower extremities strength. In ON-LINE regime and during sampling (1000 Hz) the researcher obtains information on the quality of test performance immediately after the take-off.

The solution of test analysis of repeated jumps, on the basis of scanned function $F_R(t)$ (Fig. 3C) is more demanding and presently a software relating to this task is in the developmental phase.

Another potential possibility to assess tested movement actions on the sledge that are also in developmental phase is the analysis of scanned function trajectory time s(t). Recorded change of cart position and the examined person in dependency on time – function s(t) forms the basis for analysing the tested take-off. The solution procedure of this task is in principle shown in Fig. 7. We assume that the result of trajectory analysis s(t) will be an array of information pertaining to movement performance from the perspective of time, trajectory, speed, work and the achievement that should be, in principle, congruent with the data obtained by analysing the reaction force F_R. The use of different variations for assessing the take-off on sledge evolves from the character of the solved task and the particular system provides a wide scale of research and application possibilities.

Practical implications

The presented sledge system is a laboratory apparatus functioning in the diagnosis of take-off abilities – muscle force of lower extremities. It allows for the testing of symmetric movements of lower extremities in different variations of take-off, take-off from one leg (one leg model) and can be used for testing mechanical features of sporting equipments (balls, shoes, sport surfaces etc.) The apparatus can be used not only for testing the quality of take-off abilities but also as a means for regulated training connected with immediate feedback control.

The system is equipped with two types of scanners (force plate, 2 systems for measurement of sliding cart trajectory) that allow kinematic and dynamic analyses of movement.

The apparatus allows modelling of large load variables that an examined person overcomes during different take-off variations. The size of the load moves from small values to similar or larger values with respect to the subject's weight. Modelling of load is given by a combination of inclination of the sliding cart plane and additional loads.

The stationary laboratory sledge apparatus allows application of other diagnostic methods (function examination, EMG etc.) and creates conditions for complex evaluation of an athlete in highly standardised movement situations.

The presented method of dynamic analysis of reaction force $F_R(t)$ designed for analysis of single take-offs provides a large amount of data on time, force, speed and trajectory field of movement course (total 28 variables). In ON-LINE regime and during sampling frequency of 1000 Hz, the experimenter or the coach is able to obtain immediate information on the quality of examined movement action.

Acknowledgement

The research has been supported by the MSMT CR Project No. MSM 155100016.

References

Aura O, Komi PV (1986a). Mechanical efficiency of pure positive and pure negative work with special reference to the work intensity. *Int J Sports Med*, 7: 44.

Aura O, Komi PV (1986b). Effects of pre-stretch intensity on mechanical efficiency of positive work and on elastic behaviour of skeletal muscle in stretch-shortening cycle exercise. *Int J Sports Med*, 7: 137.

Bosco C, Ito A, Komi PV, Luhtanen P, Rahkila P, Rusko H, Viitasalo JT (1982). Neuromuscular function and mechanical efficiency of human leg extensor muscles during jumping exercise. *Acta Phys Scand*, 114: 543-550.

Brüggemann G P (1994). Biomechanical considerations on jumping in sports - an approach to fundamental understanding. In A. Barabás & G. Fabián (Eds.), Proceedings of the 12th International Symposium on Biomechanics in Sports (pp. 292-294). Budapest: Hungarian University of Physical Education.

Gollhofer A, Komi PV, Fujitsuka N, Miyashita M (1987a). Fatigue during stretch-shortening cycle exercises. I. Changes in mechanical performance of human skeletal muscle. *Int J Sports Med*, 8: 71-78.

Gollhofer A, Komi PV, Fujitsuka N, Miyashita M (1987b). Fatigue during stretch-shortening cycle exercises. II. Changes in neuromuscular activation patterns of human skeletal muscle. *Int J Sports Med*, 8: 38-47.

Komi PV (1984). Physiological and biomechanical correlates of muscle function: effects of muscle structure and stretch-shortening cycle on force and speed. In R.L. Terjung (Ed.), Exercise and Sport Sciences Reviews, Vol. 12 (pp. 81-121). Lexington: Collamore Press.

Komi PV (1992). Stretch-shortening cycle. In P.V. Komi (Ed.), Strength and Power in Sport (pp. 169-179). Oxford: Blackwell Scientific Publications.

Mekota K, Blahuš P (1983). Motorické testy v telesné výchove. Praha: SPN.

Norman RW, Komi PV (1979). Electromyographic delay in skeletal muscle under normal movement conditions. *Acta Physiol Scand*, 106: 241.

Stromšík P, Vaverka F, Elfmark M (2002). The reliability and validity of jump testing by the sledge system. In K. Jelen, S. Kušová, M. Chalupová and J. Otáhal (Eds.), Proceedings of the International Conference on Biomechanics of Man 2002 (pp. 155-158). Prague: Charles University.

Vaverka F (2000). Vertical jump – a suitable model for problems in biomechanics and motorics. In F. Vaverka & M. Janura (Eds.), Proceedings of the conference Biomechanics of Man 2000 (pp. 213-216). Olomouc: Univerzita Palackého.

Vaverka F, Janura M (1998). Comparison of the force-time structure of the vertical jump between men and women. In J. D. Wilkerson, K. M. Ludwig & W. J. Zimmerman (Eds.), Proceedings of the 15th International Symposium on Biomechanics in Sports (pp. 75-80). Denton, TX: Texas Woman's University Press.

Vaverka F, Novosad J, Salinger J (1980). Merení finální charakteristiky skoku pomocí silového impulzu a doby bezoporové fáze skoku. *Teorie a praxe telesné výchovy*, 28(1): 46-54.

Vaverka F, Salinger J, Novosad J (1979). Testování vertikálních skoku. *Teorie a praxe telesné výchovy*, 27(12): 732-739.