In order to vary the energy level of the subject prior to the jump, 5 different situations were utilized. In one situation the subject jumped from a semi-squatting position. No preparatory counter-movement was allowed. In a second situation the subject was allowed a preparatory counter-movement, starting standing erect on the platform.

In the last three situations the subject jumped down from one of three different platforms, I to III, the heights of which were 0.233, 0.404 and 0.690 m, respectively, above the surface of the force-platform. The jump down was immediately, without stop, continued in the vertical upward jump. Examples of the records obtained during the jumps are shown in Fig. 1.

The height of the jump—*i.e.* the vertical lift of the subject's center of gravity—was calculated from the time of flight, t_f seconds, measured directly from the records (distance 4 to 5 in Fig. 1). This presupposes that the subject leaves and lands on the platform with the body held in the same position. The subjects, therefore, were instructed to keep the legs nearly extended at landing and to keep the arms at the sides with only slightly flexed elbows.

In the flight the subject will take off with a certain upward-directed velocity, v_f m/s, which will decrease and become zero at the apex of the jump. During the subsequent downward movement velocity will again increase and reach numerically the same value, v_f m/s, at touch-down. The time spent moving upwards or downwards will be the same and equal to $\frac{1}{2} t_f$ s. As the acceleration of gravity is 9.81 m/s², it follows that $v_f = \frac{1}{2}t_f \times 9.81$ m/s.* The average velocity, upwards or downwards, will be $\frac{1}{2}v_f$ m/s or $\frac{1}{4}t_f \times 9.81$ m/s. The distance, d, covered at this average velocity in the time $\frac{1}{2}t_f$—*i.e.* the height of the jump—will then be $\frac{1}{4}t_f \times 9.81 \times \frac{1}{2}t_f = 1/8\ (t_f)^2 \times 9.81$, or $d = 1.226 \times (t_f)^2$ m.

At the top of the flight the increase in energy level of the jumper over that in the position standing on the force-platform will then be $w \times d$ kpm, in which w is the weight of the subject in kp.

Correspondingly, the increase in energy level of the subject at the moment he reaches the force-platform after jumping down from platforms I, II and III respectively (at point 1 in Fig. 1 C), can be calculated as $w \times h$ kpm, in which w is the weight in kp of the subject and h is the height in m of platforms I—III.

In the case of jumping after a preparatory counter-movement (Fig. 1 B) the maximum increase in energy level of the subject, *i.e.* at point 2, is calculated as kinetic energy from $E_{kin} = \frac{1}{2}mv^2$. In this formula m, the inertial mass of the subject, equals weight divided by the acceleration of gravity *i.e.* w/9.81, and velocity, v, is calculated from $F \times t = m \times v$.

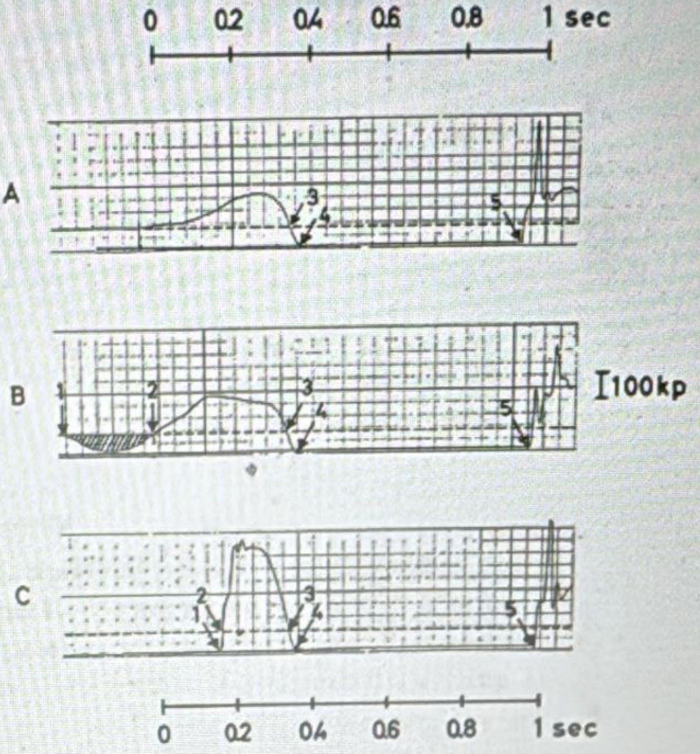

Fig. 1. Examples of records from force-platform. Ordinate: force in kp; abscissa: time in sec. In A the subject jumped from a semi-squatting position. In B the subject made a preparatory counter - movement, starting standing erect on the force-platform. In C the subject jumped down from a platform 0.233 m above the force-platform. 1 indicates the start of the downward movement when in contact with the force-platform. 2 is the time of maximum downward velocity; 3 indicates the time of maximum upward velocity; 4 the time of take-off, and 5 the time of touch-down. The dotted line indicates the weight of the subject.

TABLE I. Height of vertical jump 'd' in m, calculated from the time of flight (see text) without or with preparatory movements.

subject				after jumping down from platforms I—III		
no., sex	body weight kp	from squatting position	with a counter-movement	I, height 0.233 m	II, height 0.404 m	III, height 0.690 m
1 m.	75.8	0.450	0.515	0.515	0.515	0.491
2 m.	87.5	0.316	0.307	0.320	0.307	0.345
3 m.	70.1	0.320	0.358	0.372	0.394	0.404
4 m.	61.5	0.485	0.519	0.538	0.555	0.557
5 m.	70.0	0.444	0.484	0.495	0.529	0.473
6 m.	73.6	0.356	0.342	0.340	0.354	0.357
7 m.	69.7	0.443	0.408	0.441	0.429	0.442
8 m.	79.1	0.340	0.392	0.399	0.432	0.356
9 m.	79.4	0.342	0.370	0.399	0.386	0.372
10 m.	91.1	0.466	0.503	0.470	0.473	0.470
11 m.	83.5	0.399	0.413	0.413	0.424	0.412
12 f.	57.6	0.323	0.351	0.350	0.388	0.301
13 m.	71.0	0.366	0.448	0.486	0.517	0.473
14 f.	59.6	0.218	0.215	0.228	0.245	0.206
15 f.	62.6	0.323	0.304	0.311	0.307	0.298
16 m.	72.0	0.370	0.355	0.349	0.386	0.396
17 m.	74.0	0.410	0.401	0.425	0.442	0.384
18 f.	59.1	0.250	0.269	0.277	0.280	0.253
19 f.	51.0	0.340	0.381	0.389	0.403	0.410
$\bar{X}$	71.0	0.366	0.386	0.396	0.408	0.389
SD	—	0.071	0.083	0.083	0.086	0.086
SE	—	0.016	0.019	0.019	0.019	0.019

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From the Laboratory for the Theory of Gymnastics, August Krogh Institute, University of Copenhagen, Denmark

Storage of Elastic Energy in Skeletal Muscles in Man

By

Erling Asmussen and Flemming Bonde-Petersen

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Abstract

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The question, if muscles can absorb and temporarily store mechanical energy in the form of elastic energy for later re-use, was studied by having subjects perform maximal vertical jumps on a registering force-platform. The jumps were performed 1) from a semi-squatting position, 2) after a natural counter-movement from a standing position, or 3) in continuation of jumps down from heights of 0.23, 0.40, or 0.69 m. The heights of the jumps were calculated from the registered flight times. The maximum energy level, E_{neg}, of the jumpers prior to the upward movement in the jump, was considered to be zero in condition 1. In condition 2 it was calculated from the force-time record of the force-platform; and in condition 3 it was calculated from the height of the downward jump and the weight of the subject. The maximum energy level after take-off, E_{pos}, was calculated from the height of the jump and the jumper's weight. It was found that the height of the jump and E_{pos} increased with increasing amounts of E_{neg}, up to a certain level (jumping down from 0.40 m). The gains in E_{pos} over that in condition 1, were expressed as a percentage of E_{neg} and found to be 22.9 % in condition 2, and 13.2, 10.5, and 3.3 % in the three situations of condition 3. It is suggested that the elastic energy is stored in the active muscles, and it is demonstrated that the muscles of the legs are activated in the downward jumps before contact with the platform is established.

The elastic properties of muscles have been known and studied extensively for many years. The original concept of *e.g.* Levin and Wyman (1927), *viz.* that the energy liberated at contraction was immediately stored as elastic energy in the series elastic components for subsequent use in performing work, has been abandoned, not least after the discovery of the "Fenn effect" (Fenn and Marsh 1935). Nevertheless muscle elasticity has continued to arouse the interest of muscle physiologists, and its possible role as a buffer and temporary store of mechanical energy has anew been brought to the attention of work physiologists *e.g.* by the studies of Cavagna *et al.* (1968). One way of investigating this possible function of the elastic component in muscle is to compare the release of external mechanical energy without and with a previous stretching of the involved muscles. This was done by Marey and Demeny (1885) who compared the heights of vertical jumps performed without and with a preliminary counter-movement and found the height to be higher in the latter case. Recently Cavagna *et al.* (1971) repeated these experiments, using a force-platform

Key words: elastic energy; negative work; vertical jump; force-platform.