**Introduction**

Muscles can be active both in static and kinetic conditions. In the former, during an isometric contraction, the muscle does not shorten; during a concentric contraction it shortens, and during an eccentric contraction it elongates. Human movement is never confined to muscle work involving only one type of muscular contraction. Very often external conditions affect the muscle length (running, jumping) before the mechanical work takes place. Most training programs are based on exercises in dynamic conditions and involve both concentric (CON) and eccentric (ECC) muscle actions. A great number of studies have shown that a combination of CON and ECC muscle actions yields the best training results [1, 2]. Training exercises can be grouped into single joint movements or multiple joint movements; principal exercises or auxiliary exercises; and exercises of the whole body or a specific part of it. These oppositions are based on the number and area of engaged muscles. Single joint exercises are used for isolated strengthening of selected muscle groups [3]. Their main advantage is low risk of injuries due to their low technical complexity. Multiple joint exercises are more demanding from the standpoint of human motor performance. The efficiency of power training after single and multiple joint exercises was the aim of the study.

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**ABSTRACT**

**Purpose.** Single joint (open kinetic chain) and multiple joint (closed kinetic chain) exercises have been recommended in rehabilitation of patients with anterior knee pain. Single joint exercises are common exercises to strengthen selected muscle groups. The advantage of single joint exercises is a low risk of pain due to their limited technical complexity. Multiple joint exercises are more demanding from the standpoint of human motor performance. The efficiency of power training after single and multiple joint exercises was the aim of the study. **Basic procedures.** Forty eight men constituted the study sample (aged 22 ± 0.8 years, body weight – 78.3 ± 6.4 kg, body height 183 ± 5.6 cm). They were informed about the experimental procedure as well as the purpose of the study, and gave their consent to take part in the experiment. That study was approved by the local research ethics committee. After control measurements the participants were randomized into four groups (n = 12 each): two groups performing multiple joint exercises (A – jumps on an inclined plane, B – vertical jumps), and two single joint exercises (C – knee extensions with linear resistance load – elastic loads, D – knee extensions with inertial loads). The exercises were carried out in four-week exercise sessions, for five days a week. 4 sets of 10 reps (jumps or extensions) with 120-second intervals were applied during each session. The counter movement jump power (on a Kistler force plate with BioWare 4.0 software), during isokinetic knee motion at 240, 180, 60 and 30 deg/s (Biodex Medical System 3 Pro) and EMG (Mega Electronics System) of the Rectus Femoris and Vastus Lateralis muscles were recorded seven times (once before, three times during and three times after training). **Main findings.** The external load for single and multiple joint exercises was adjusted by individual power of motion. However the training volume (external work) was lowered twice during training with single joint exercises. Muscle force during isokinetic tests was significantly correlated with velocity achieved during training. Therefore the homogeneity of the movement structure between training and control exercises is required. **Conclusions.** Velocity of motion during exercise and time of muscle work are the most important factors determining efficiency of single- and multiple-joint exercises.

**Key words:** power, training, single- and multiple-joint exercises, EMG
Professional literature has lacked comparative studies of training exercises involving different groups of muscles. The aim of the present work was to assess the efficiency of power training involving single joint and multiple joint exercises.

Material and methods

The study sample consisted of 48 third-year students of the Józef Piłsudski University of Physical Education in Warsaw, aged 22–24 years, divided into four groups of 12 subjects each. Table 1 presents subjects’ mean body mass and body height. No significant differences in subjects’ body weight or body height were noted in regard of their membership in a given group or duration of the experiment (F (18, 264) = 0.781, p = 0.722).

Students from groups A and B performed multiple joint exercises, while students from groups 3 and 4 single joint exercises. Subjects from group A trained multiple jumps on an inclined plane, group B – multiple vertical jumps, group C – knee extensions with linear resistance load – elastic loads, and group D – knee extensions with inertial loads. External resistance was used in particular groups, allowing the subjects to develop peak power. During the initial measurements the amount of resistance was determined for each exercise group: extra weight for the exercises on the inclined plane (A), extra weight and adjustable height of the hurdle for multiple vertical jumps (B), the number of expanders for knee extensions with elastic loads (C) and the number of stacked weights for knee extensions with inertial loads (D).

The tests lasted seven weeks. For four weeks the subjects took part in exercises five times a week (weekdays). Each Monday, before exercises the following measurements were taken: power and height of a vertical counter movement jump (CMJ) on a Kistler force plate; power of knee extensors in isokinetic conditions with the aid of Biodex System 3 Pro dynamometer, and bioelectrical activity of the Rectus Femoris (RF) and Vastus Lateralis (VL) muscles. The EMG was carried out with the aid of the ME 3000 P4 muscle tester (Mega Electronics System, Finland). The Average EMG signal (AEMG) and EMG Mean Power Frequency (MPF) were calculated using RAW spectrum analysis through the Fast Fourier Transform (FFT).

Mechanical work performed by all the groups was not identical (Tab. 2). The observed differences depended, first of all, on the mobility of the locomotor system and contribution of the muscles engaged. The highest concentric work was performed by subjects from group A. The results from group B were 21% lower, which was related to the greater mobility of the locomotor system during the multiple vertical jumps. The work results in groups C and D were 68% and 71% lower, respectively, which was connected with the limited activity of single joint exercises (Tab. 2). Besides the subjects from these groups did not perform eccentric exercises.

In the statistical analysis of mean results in the groups an analysis of variance (ANOVA) and multivariate analysis of variance (MANOVA) for repeated measures were carried out as well as the Friedman test.
Results

An increase in power developed by the knee extensors in isokinetic conditions was observed during exercises with only one velocity of movement (Fig. 1).

During exercises with the velocity of 240º/s, an increment in power was noted from the third week. Statistically significant increases in power were noted in group C already in the first week after the completion of training ($p = 0.0246$). After the training the power results in groups C and D were 13% higher than at the beginning of the experiment ($p < 0.001$).

The lowest increase was noted in group B (7%), which was nevertheless statistically significant ($p = 0.0488$). During the exercise as well as a week after the training, results in particular groups point to some similarities in power increase, in terms of the structures of control movement and exercise movement. This is particularly visible in groups performing single joint exercises (C and D).

The effects of training with different exercises were also assessed with measurements of power during counter movement jumps (CMJ) (Tab. 3). At the beginning the measurements did not differ significantly. The highest increase was noted in group B (16.3% on the 42nd day of training). In group A the peak increase of power was observed on the 36th day (15.6%), however by the end of training it decreased by about 7.6%.

The impact of training with loads allowing development of peak power on the coordination mechanisms of muscle contraction was assessed with two EMG indices for the concentric movement phase: the Average EMG (AEMG) and EMG Mean Power Frequency (MPF).

Figure 2 presents the mean increases of EMG MPF for the Rectus Femoris muscle (RF) and Vastus Lateralis muscle (VL). The EMG MPF changes for the RF muscle were statistically non significant. In the case of the VL muscle and the Wilcoxon signed rank test for EMG results, which were not normally distributed.

![Figure 1. Development of power (%) on selected days of the experiment under isokinetic conditions at 240 deg/s, 180 deg/s, 60 deg/s and 30 deg/s](image)

**Table 3. Mean peak power (± SD) during counter movement jumps on individual days of training**

| Group | Day of training | 1<sup>st</sup> | 11<sup>th</sup> | 18<sup>th</sup> | 25<sup>th</sup> | 32<sup>nd</sup> | 36<sup>th</sup> | 42<sup>nd</sup> |
|-------|----------------|--------------|---------------|--------------|--------------|--------------|--------------|--------------|
| A     |                | 2520 ± 452   | 2660 ± 382    | 2705 ± 453<sup>a</sup> | 2734 ± 510<sup>b</sup> | 2815 ± 490<sup>c</sup> | 2914 ± 497<sup>d</sup> | 2710 ± 395<sup>e</sup> |
| B     |                | 2735 ± 450   | 2969 ± 460<sup>f</sup> | 3018 ± 510<sup>g</sup> | 2872 ± 501   | 3033 ± 523<sup>h</sup> | 3028 ± 512<sup>i</sup> | 3182 ± 504<sup>j</sup> |
| C     |                | 3039 ± 539   | 3054 ± 513    | 3045 ± 546    | 3057 ± 481   | 3037 ± 475   | 3109 ± 459   | 3008 ± 557   |
| D     |                | 2823 ± 436   | 2775 ± 475    | 2849 ± 532    | 2698 ± 531   | 2886 ± 541   | 2737 ± 407   | 2761 ± 419   |

* $p = 0.0295$, $b$ $p = 0.0146$, $c$ $p = 0.0007$, $d$ $p = 0.0001$, $e$ $p = 0.0290$, $f$ $p = 0.0001$, $g$ $p = 0.0001$, $h$ $p = 0.0001$, $i$ $p = 0.0047$, $j$ $p = 0.0076
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muscle the MPF increases noted can be divided into two exercise categories: multi joint exercises (A and B) and single joint exercises (C and D). In the early part of the training the MPF decreased significantly in groups A and B (p < 0.05). In group B the observed decrease was by 15%. This effect was not present in the first week of training in groups C and D, but after that the MPF also decreased reaching the lowest value on the last day of training. After the exercises the MPF was slightly higher than at the start of the training in groups C and D (1.6% and 3.8%, respectively). The MPF in groups A and B was lower on the 32nd day of training than at the start (7.5%). No MPF changes were statistically significant.

After the first week of training the AEMG increments were highly differentiated in the case of Vastus Lateralis muscle (VL) (Fig. 2).

The highest statistically significant increase was noted in group B (12%). The observed significant AEMG differences between the groups were related to the bioelectrical muscle activity in group A. The AEMG of the Rectus Femoris muscle (RF) and Vastus Lateralis muscle (VL) in the 32nd week of training in group A was significantly higher than in the other groups (p = 0.002 for AEMG-RF and p = 0.003 for AEMG-VL). Statistically significant AEMG changes were found for the RF in group A (p = 0.00048) and B (p = 0.0158), and in the case of VL only in group A (p = 0.0069).

Discussion

The statistically significant differences resulting from the mobility of the open kinetic chain are only noted in the values of power developed during counter movement jumps (CMJ) (Tab. 3). The highest peak power was developed by subjects from groups A and B, who performed multi joint exercises. The large difference in power results between groups A and B and groups C and D was related to the similarities between the mobility of training exercises with the ways the counter movement jumps are performed. The differences in results of power developed during an isolated knee movement in isokinetic conditions depended on the velocity of knee exercises. Mastalerz [5] showed in an earlier study with the use of the same exercises that the peak values of knee extension velocity on an inclined plate were two times higher than in other types of exercises. Although the subjects from group B failed to achieve the highest increase of mean power during knee extension, their velocity results of knee exercises confirm the impact discussed above.

Another factor determining the development of power in isokinetic conditions was the duration of the concentric phase of exercises as demonstrated by the EMG. To recruit effectively fast twitch fibers (Type II) an appropriately high level of stimulation frequency is necessary [6]. A short concentric phase of exercise in
group A could have prevented such nervous stimulation of the fast twitch muscle fibres. This effect may explain the decrease in EMG MPF during training also in the other groups of subjects. It can be also noted that the results varied, depending on the muscle (Vastus Lateralis or Rectus Femoris), which confirms results of earlier studies pointing to the functional differences of both muscles [4, 5]. Also Mastalerz and Urbanik [7] in their study of drop jumps considered the duration of contact with the floor during the swing and take-off phases (as well as a part of the shock absorption phase in drop jumps) to be the main factor affecting the exercise results. The key role in stretch–contraction muscle exercise is played by trained mechanisms associated with the reactivity of the system of locomotion to external stimuli. These mechanisms are skills of reducing the time of the shock absorption phase. A skill that would increase simulation frequency is contracting muscles before the landing phase. Such a mechanism was described by Komi and Gollhofer [8] in their examination of the triceps calf muscle, lateral vastus muscle and – in particular – soleus muscle whose activity preceded the phase of take off during a drop jump for 40 ms. Similar results were obtained by Voigt et al. [9] for multiple jumps with a short time of contact with the floor.

Conclusions

The test results achieved after training were affected by two characteristics of movement structure: velocity of movement and time of muscle work. After exercises on an inclined plane a significant increase in power was observed during knee extensions in isokinetic conditions. This was due to the subjects’ development of the highest movement velocity at the knee joint during training. The other important factor affecting the power developed in isokinetic conditions is the time of the concentric phase of exercise as shown by the EMG. In the group of subjects performing multiple jumps, this time as well as insufficient recruitment of fast twitch fibres explain the decrease in EMG MPF for the Vastus Lateralis muscle. The MPF for the Rectus Femoris muscle was 50% lower, especially during training. This can be explained by the muscle’s function as a stabilizer and controller of the movement. The significant differences resulting from the mobility of the locomotor system, determined by the number of joints involved in training, were noted between the results of power reached during the counter movement jumps. In both groups performing single joint exercises only, the maximum increase of power amounted to 2.5%, whereas in groups with similar mobility performing control exercises it was higher than 15%.

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