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# Effect of high-intensity endurance training on isokinetic muscle power

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**Summary.** The purpose of this study was to determine the effects of high-intensity endurance training on isokinetic muscle power. Six male students majoring in physical-education participated in high intensity endurance training on a cycle ergometer at 90% of maximal oxygen uptake ($\dot{V}_{O_{2\max}}$) for 7 weeks. The duration of the daily exercise session was set so that the energy expenditure equalled 42 $kJ \cdot kg^{-1}$ of lean body mass. Peak knee extension power was measured at six different speeds (30°, 60°, 120°, 180°, 240°, and $300° \cdot s^{-1}$) with an isokinetic dynamometer. After training, $\dot{V}_{O_{2\max}}$ increased significantly from mean values of $51.2\ ml \cdot kg^{-1} \cdot min^{-1}$, SD 6.5 to $56.3\ ml \cdot kg^{-1} \cdot min^{-1}$, SD 5.3 ($P < 0.05$). Isokinetic peak power at the lower test speeds (30°, 60° and $120° \cdot s^{-1}$) increased significantly ($P < 0.05$). However, no significant differences in muscle peak power were found at the faster velocities of 180°, 240°, and $300° \cdot s^{-1}$. The percentage improvement was dependent on the initial muscle peak power of each subject and the training stimulus (intensity of cycle ergometer exercise).

**Key words:** Endurance training – Isokinetic muscle power – 90% $\dot{V}_{O_{2\max}}$

## Introduction

According to previous studies, the changes in various kinds of muscular output (maximal isometric strength, isokinetic power, dynamic power) following strength training of muscle are very specific to the training mode (especially resistance and/or speed) (Rasch and Morehouse 1957; Moffroid and Whipple 1970; Sale and McDougall 1981; Coyle et al. 1981; Kanehisa and Miyashita 1983a; Kanehisa and Miyashita 1983b). From this point of view, endurance training is regarded as low-resistance, moderate speed, training of the muscle concerned. Therefore, previous studies would not have been expected to find significant effects of endurance training on maximal isometric muscle strength (Holloszy and Booth 1976; Gettman et al. 1978), because training of this type is not known to induce muscle hypertrophy.

However, with regard to specificity of training speed, Lesmes et al. (1978) and Coyle et al. (1981) used isokinetic test techniques to show that the effects of strength training are specific to training speed. It was hypothesized that isokinetic exercise testing would be able to detect the effects of endurance training on isokinetic peak power specifically at the test speeds that would be experienced most frequently during endurance training. The purpose of this study, therefore, was to determine the effects of high-intensity endurance training on isokinetic muscle peak power.

## Methods

*Subjects.* Following a detailed explanation of the purpose, potential benefits and risks associated with participation in this training study, six male students majoring in physical education volunteered to take part and signed forms of informed consent. Their mean values for age, height, mass, percentage body fat, and maximal oxygen uptake ($\dot{V}_{O_{2\max}}$) are shown in Table 1.

**Table 1.** Characteristics of the subjects

| | Age (year) | Height (cm) | Body mass (kg) | Body-fat (%) | $\dot{V}_{O_{2\max}}$ ($ml \cdot kg^{-1} \cdot min^{-1}$) |
|---|---|---|---|---|---|
| Mean | 23 | 171.9 | 63.0 | 12.2 | 51.2 |
| SD | 2 | 6.4 | 8.8 | 4.1 | 5.2 |

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*Isokinetic test.* A Cybex II system (Lumex Inc., New York) was used to evaluate maximal peak power before, during, and after training. Each subject was seated at a test bench and secured by placing restraining straps about the hip and thigh to minimize extraneous movement. The central axis of the lever was then aligned with the anatomical axis of rotation of the knee. Damped (Cybex II recorder dam setting 1) power curves were obtained at 30°, 60°, 120°, 180°, 240°, and 300° $\cdot s^{-1}$. The highest point of the power curve was recorded as muscle peak power. The subjects performed three extensions at each test velocity and the highest scores were recorded. A 1-min rest was given between all the maximal extensions. Calibration of the dynamometer before and after each test was accomplished by placing known weights on the lever arm.

*Maximal oxygen uptake.* The $\dot{V}_{O_{2\,max}}$ was determined by an open-circuit method during cycling on a mechanically-braked ergometer (Monark-Crescent AB, Varburg, Sweden) using the progressively increasing load method (Atomi and Miyashita 1980) on every Monday during the training period.

*Anthropometry.* Lean body mass (LBM) and percentage body fat were measured using an underwater method (Brozeck et al. 1963).

A cross-sectional area of the thigh muscle was measured using an ultrasonic technique at one-third of the distance between the superior surfaces of the trochanter major and the knee (Ikai and Fukunaga 1968).

*Training protocol.* The subjects were required to exercise 5 days a week for 7 weeks. The interval training consisted of several sessions on the mechanically-braked cycle ergometer at a power output that required 90% of each subject's $\dot{V}_{O_{2\,max}}$. The pedalling frequency was 50 rpm. The intensity of the training exercise for each individual was determined for each subject by calculating the regression of steady-state oxygen uptake on exercise intensity. Duration was determined for each individual so that the energy expenditure for each day of training amounted to 42 $kJ \cdot kg^{-1}$ (10 $kcal \cdot kg^{-1}$) of LBM, assuming that one litre of oxygen consumption was equal to 5 kcal. Each training exercise was continued until the subjects became unable to pedal at the fixed rate. After 5 min of rest, the subjects recommenced exercise at the same intensity. Daily training was terminated when the total exercise time amounted to the prescribed training time. The mean energy expenditure was about 2100 $kJ \cdot day^{-1}$ (500 $kcal \cdot day^{-1}$). As the $\dot{V}_{O_{2\,max}}$ of each subject was observed to increase week by week, so his power output on the cycle ergometer was increased as was required to produce 90% $\dot{V}_{O_{2\,max}}$.

*Statistics.* Conventional statistical methods were used for calculation of means and standard deviations (SD). Changes from pre- to post-training were tested by *t*-test for paired observations. All comparisons were regarded as statistically significant at $P < 0.05$.

## Results

After training, $\dot{V}_{O_{2\,max}}$ increased significantly from 51.2 $ml \cdot kg^{-1} \cdot min^{-1}$, SD 6.5 to 56.3 $ml \cdot kg^{-1} \cdot min^{-1}$, SD 5.2 ($P < 0.05$). Table 2 shows the pre- and posttraining values of cross-sectional area of the leg extensors and the maximum circumference of the thigh. These two parameters did not change significantly with training ($P > 0.05$).

Table 3 shows the alterations in peak power obtained at six different test speeds. At the faster test speeds, small increases were observed in some subjects whose initial values were low, while there were no improvements in the subjects who had relatively high initial values. Therefore, no statistically significant changes were obtained at the faster test speeds. Significant increases were observed at 30°, 60° and 120° $\cdot s^{-1}$. Figure 1 shows the relationship between the percentage increase in peak power at 120° $\cdot s^{-1}$ and the ratio of power output of the training exercise to the initial isokinetic muscle peak power at that speed. There was a significant correlation ($r = 0.86$, $P < 0.05$) between these

**Table 2.** Pre- and post training values of cross-sectional area and maximum circumference of leg extensor muscles

| | Pre-training | | Post-training | |
|---|---|---|---|---|
| | mean | SD | mean | SD |
| Cross-sectional area of leg extensor muscles ($cm^2$) | 93.2 | 9.3 | 87.9 | 12.4 |
| Maximum circumference of thigh muscles (cm) | 52.8 | 3.4 | 52.6 | 3.7 |

**Table 3.** Changes in peak power at six different speeds per cross-sectional area of leg extensor muscles ($W \cdot cm^2$)

| Test speed (° $\cdot s^{-1}$) | 300 | 240 | 180 | 120 | 60 | 30 |
|---|---|---|---|---|---|---|
| Pre-training values | | | | | | |
| mean | 5.49 | 5.41 | 4.65 | 3.66 | 2.14 | 1.05 |
| SD | 0.73 | 0.75 | 0.66 | 0.48 | 0.29 | 0.18 |
| Post-training values | | | | | | |
| mean | 5.70 | 5.70 | 5.02 | *4.01 | *2.40 | *1.24 |
| SD | 0.42 | 0.29 | 0.27 | 0.36 | 0.38 | 0.19 |

* = significant differences from the pre-training values ($P < 0.05$)

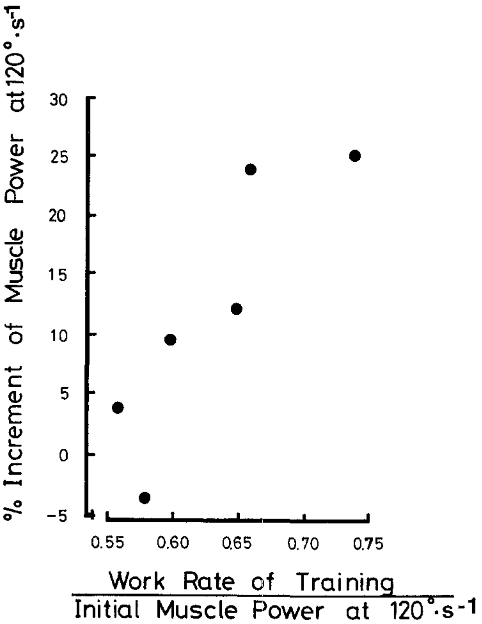

**Fig. 1.** Relationship between percentage increases in peak power at 120° $\cdot s^{-1}$ and the ratio of power output of training exercise to initial value of isokinetic muscle power at 120° $\cdot s^{-1}$. $r = 0.86$ ($P < 0.05$)

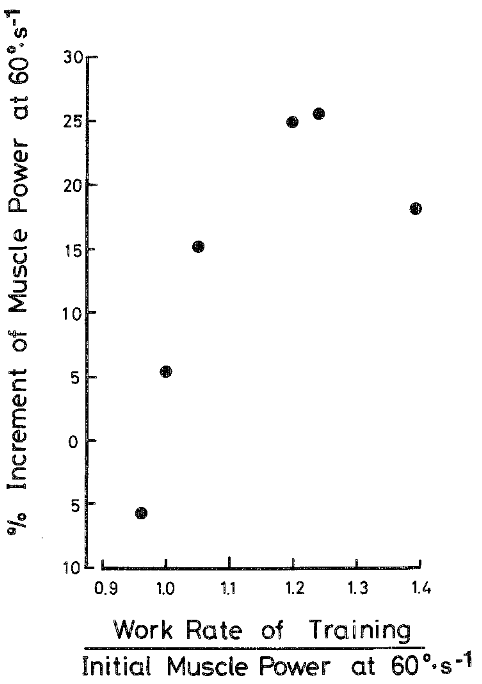

**Fig. 2.** Relationship between percentage increases in peak power at 60° $\cdot$ $s^{-1}$ and the ratio of power output of training exercise to initial value of isokinetic muscle power at 60° $\cdot$ $s^{-1}$. $r = 0.74$ ($P < 0.05$)

two parameters. This relationship indicates that the greater the intensity of training exercise relative to the initial isokinetic peak power, the greater the improvement in isokinetic peak power at that speed. Another significant correlation between these two parameters was observed at the test speed of 60° $\cdot$ $s^{-1}$ ($r = 0.74$, $P < 0.05$, Fig. 2).

## Discussion

The endurance training adopted in the present study may be regarded as low resistance, moderate speed, muscle training from the view point of muscle strength training. Many previous studies, including Hakkinen and Komi (1986), have shown that heavy resistance isometric training induces muscle hypertrophy and a large increase in maximal isometric voluntary contraction, and low resistance high speed training has no effect on maximal isometric strength and cross-sectional area of the muscles. Because isokinetic measurement rather than isometric measurement was used, the present study, for the first time, showed the effects of so-called endurance training on one property of muscle (isokinetic peak power).

Although in this study training did not increase the cross-sectional area of whole muscles, as measured by an ultrasonic technique, there is a possibility that a change may have occurred in the ratio of the cross-sectional areas of specific muscle fibre types. Gollnick et al. (1974) observed that type II fibres began to be recruited at an exercise intensity above 85% of $\dot{V}_{O_{2\max}}$. Vøllestad and Blom (1985) reported that, at an exercise intensity of 91% $\dot{V}_{O_{2\max}}$, all fibres of type I, significant numbers of type IIA, and some fibres of type IIB were recruited. From these observations, it would appear that type I fibres would have been mainly recruited in our training programme (90% $\dot{V}_{O_{2\max}}$) and would have become larger after the high intensity endurance training (Gollnick et al. 1972). This change may have been induced by a hormonal effect, because, during the period of the present training study, serum cortisol concentration (which enhances muscle protein degradation) in the early morning was shown to have increased (Tabata et al. 1989). Type II fibres are more sensitive to cortisol than type I fibres (Goldberg and Goodman 1969). Therefore, there is a possibility that type I fibres would have become larger and type II fibres smaller after the training (Gollnick et al. 1973). However, at lower test speeds, where increases in isokinetic muscle power were observed in the present study, Thorstensson (1976) has shown no significant difference in isokinetic peak power of the knee extensor muscle between subjects whose muscles were mainly composed of FT (fast twitch) fibres and those with mainly ST (slow twitch) fibres. Consequently, postulated changes in the ratio of the cross-sectional areas of specific muscle fibre types should not have affected the increases in isokinetic peak power at the lower test speeds.

A specific improvement in neuro-muscular co-ordination may explain the increased isokinetic muscle peak power at the lower speeds. Even if muscle mass did not increase, highly-synchronized central commands after training could have increased isokinetic peak muscle power. Milner-Brown et al. (1975) and Komi et al. (1978) have indicated that training increases the number of motor units recruited and/or brings about a more synchronous firing of motor units. In other words, the highly synchronous firing of motor units is a key factor to increasing power output during dynamic contraction (isokinetic contraction). In the present study, the calculated mean contraction speed of cycling at 50 rpm is about 140° $\cdot$ $s^{-1}$, i.e. in the lower range of test speeds where increases of isokinetic muscle power were observed. This result may suggest that the coordination of muscle fibre recruitment was improved at the most familiar contraction speed by the cycle ergometer exercise programme in the present study. Coyle et al. (1981) have also shown that isokinetic training effects are specific to training speed.

Further, increases of isokinetic peak muscle power at the slower speeds were observed in the present study. Lesmes et al. (1978) have also reported that isokinetic training effects on isokinetic muscle power were observed at test speeds that were lower than the training speed. The slower the test speed, the longer the time when peak power may be obtained (Thorstensson et al. 1976) and the easier it is to recruit more motor units during the time from the start of contraction to the time when isokinetic peak power is recorded. Therefore, it is not difficult to imagine that, after the subjects have become able to recruit their motor units more synchronously at the contraction speed that was experienced most frequently during training, they could produce more peak power at the slower test speeds than at the training speed. During isokinetic contraction of knee extension at $120° \cdot s^{-1}$, the time when peak power was recorded was within no more than 0.3 s after initiation of muscle contraction. Hakkinenn et al. (1985) have reported that, without improvement in maximal voluntary contraction, explosive jump training induces a faster achievement of maximal isometric force production through the activation of more motor units during the beginning of contraction (this activation was detected by electromyographic technique). These findings have been interpreted as indicating that trained subjects can more fully and quickly activate prime mover muscle in maximal voluntary contractions (Sale 1988).

Furthermore, the failure of isokinetic muscle peak power to improve at speeds faster than the training speed may be explained by the same reasoning: the subjects were unable to acquire the ability to recruit muscle fibres more fully and quickly during the shorter contraction time, because the subjects did not experience the faster contraction speeds during the training period.

Figures 1 and 2 show that the increases in isokinetic muscle power at 60 and $120° \cdot s^{-1}$ after training correlated with the ratios of power output during training to the initial muscle power at 60° and $120° \cdot s^{-1}$, respectively. This relationship suggests that improvement of muscle power by endurance training is dependent on muscle power output of the training exercise relative to the initial muscle power of each subject; that is, the increase in isokinetic peak power was greater the lower was its initial value, as one can infer from the ratios of power output of the training exercise to the initial muscle power. In other words, subjects with relatively high initial muscle power seem less capable of increasing it by means of aerobic training. The same relationship has been well documented for isometric muscle training in a previous study (Hettinger 1966).

Thorstensson et al. (1976) have reported that torque produced at any given angle of the knee is higher for isometric than for isokinetic contractions. They have also shown that the slower the test speed (including isometric contraction), the greater is the knee angle (more flexed position) at which the peak torque is recorded. Therefore, the trained subjects in the present study are likely to have produced isokinetic peak power by recruiting more muscle fibres at the knee angle at which the greatest isometric torque was obtained (Thorstensson et al. 1976) and perhaps this was the case for isokinetic contractions. This adaptation to training may also be explained by the same reasoning (specificity related to speed of training exercise): the subjects acquired the ability to recruit muscle fibres more fully at the most suitable knee angle (1) in a somewhat flexed position, and (2) that was, therefore, covered within a shorter contraction time which was inversely proportional to the isokinetic test speed, because the subjects tried to recruit more muscle fibres within a limited duration of cycling which was dependent on the pedalling frequency during the training period.

From the technical point of view, use of electronically-damped recording (Cybex II damping setting 1 = least damped position) for the purpose of recording smooth readable power (torque) tracings may have influenced the absolute values of peak power, particularly at the faster test speeds. In the present study, obviously false and high peak powers (torques) have been omitted, because they were observed before isokinetic movement of the lever arm was confirmed during the initial phase of contraction. Thus, real peak powers (torques) observed after the initial phase have been reported as results. Further, at the faster test speeds, virtually no changes in peak power was observed after training. Therefore, the use of damped recordings may not have had any influence on the major findings of the present study.

In conclusion, high-intensity endurance training improved muscle peak power at low speeds. This result suggests that improvement in isokinetic muscle power by training was specific to the speed of the training exercise and that for each subject it depended on the initial level of isokinetic muscle peak power and intensity of training exercise.

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