ORIGINAL CONTRIBUTIONS

The Acquisition of Muscular Strength: The Influence of Training Velocity and Initial VO2 Max.

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PETERSEN, S. R., MILLER, G. D., WENGER, H. A., and QUINNEY, H. A., The Acquisition of Muscular Strength: The Influence of Training Velocity and Initial, V̇O2 Max. **Can. J. Appl. Spt. Sci.** *9:4 176-180, 1984. To examing velocity specific training and to determine if V̇O2 max is related to the increase in muscular strength and power, 12 elite male swimmers (X̄ age = 18.8 years) were blocked on V̇O2 max and assigned high intensity, high velocity training. Subjects performed 2 or 3 circuits of two 20s sets at each of six variable resistance stations at a work relief ratio of 1:3. Subjects trained four times weekly, for five weeks. Loads were set to achieve limb velocities of approximately 180°·s⁻¹. Increases ($p < 0.001$) in all knee peak torques at 180°·s⁻¹ were observed. A decrease ($p < 0.02$) was noted in right knee extension at 30°·s⁻¹, while other peak torques at that velocity remained constant. Anaerobic power increased ($p < 0.001$) across the training programme. No differences in the magnitude of training effects were observed between High or Low Aerobic groups with the exception of right knee extension at 180°·s⁻¹, where the Low Aerobic group demonstrated the greater improvement ($p < 0.009$). In conclusion, this type of velocity specific training can elicit improvements in peak muscular torques at or near the training velocity. Apparently, initial V̇O2 max did not limit the attainment of muscular strength and power.*

Muscular strength, torque, training velocity, V̇O2 max, isokinetic

L'étude a été conduite afin d'étudier les effets d'un entraînement spécifique de vitesse et afin de déterminer s'il existe un relation entre le developpement de la force et de las puissance musculaire et le V̇O2 max. Le groupe experimental était constitué de 12 nageurs d'élite (X̄ age = 18.8 ans) qui étaient regroupés selon leur V̇O2 max et qui étaient soumis à un entraînement à haute intensité et haute vitesse. Les sujets devaient compléter 2 ou 3 circuits de 2 sets de 20 s à chacune des six resistances différentes avec un rapport travail: repos de 1:3. Les sujets se sont entrainés pendant 5 semaines à raison de 4 fois/semaine. Les charges de travail étaient fixées de façon à pouvoir atteindre des vitesse de mouvement d'un membre de 180°·s⁻¹. Des augmentations ($p < 0.001$) des moments maximaux de rotation du genou à 180°·s⁻¹ ont été observées. Une diminution ($p < 0.02$) a été enrégistréé pour l'extension du genou droit à 30°·s⁻¹, bien que les autres moments de rotation à cette vitesse demeurent constant. Une augmentation de la puissance anaérobie ($p < 0.001$) a été observé à la suite du programme d'entraînement. Aucune différance n'a pu être mise en évidence quant à l'importance des effets d'entraînement entre le groupe avec une haute ou une faible capacité aérobie, à l'exception du mouvement d'extension du genou droit à 180°·s⁻¹ pour lequel la plus importante amélioration a été observé chez le groupe doté d'un faible capacité aérobie ($p < 0.009$).

En conclusion, il semble que ce type de l'entraînement specifique de vitesse peut provoque des améliorations du moment maximal de rotation effectué à la même vitesse que l'entraînement ou à une vitesse similaire.

Force musculaire, moment de rotation, vitesse d'entraînement, V̇O2, isocinétique

INTRODUCTION

Many elite athletes engage in strength and power training to enhance their performance. In regard to the specificity of training effects in response to power and strength training, Sale and MacDougall

(1981) have concluded that training is specific to the movement pattern and that the training response may be specific to the joint angle or angles at which the training occurs and to the type of contraction (isometric, isotonic, or isokinetic) utilized during training. As well, Coyle and Feiring (1980) and Caiozzo et al., (1980) have suggested a velocity specific training effect where training at low velocity increased low velocity strength but had little effect on torque outputs at high velocity. Moffroid and Whipple, (1970), Lesmes et al., (1978), have also reported a greater strength transfer from high velocity training to low velocity performance than from low velocity training to higher velocity performance.

The importance of a well developed oxygen transport system for the acquistion of optimal power and strength has been suggested (Wenger, 1981). Enhanced aerobic replacement of ATP during recovery intervals, the flushing of lactate from muscle and/or the aerobic oxidation of lactate should all assist in recovery and, therefore, permit greater quality of training. The present study was undertaken to investigate the influence of intial $\dot{V}O_2$ max on the magnitude of muscular strength and power acquistion through a programme of high intensity isokinetic resistance training and to determine if the training effect is velocity specific.

METHODS

Twelve elite male varsity and winter club swimmers ($\bar{x}$ age 18.8 years) volunteered to act as subjects. The study coincided with the power phase in their annual training schedule. The training programme was designed to be comparable in type, duration, frequency, and intensity to what elite athletes might encounter in a similar training phase.

Subjects trained four times weekly over a five week period for a total of 21 sessions. The first 15 sessions consisted of two circuits and the last six sessions of three circuits on variable resistance Hydra-gym equipment. The programme was designed to achieve an overall 1:3 work-relief ratio. Each circuit consisted of two 20 second sets maximal exercise at six stations which emphasized the following movement patterns: knee flexion and extension; hip flexion and extension; elbow flexion and extension; shoulder flexion and extension; and ankle plantar flexion.

Circuits were separated by four minutes of active (walking) recovery. Subjects worked in pairs and verbal encouragement was provided to ensure maximal effort and high quality contractions at all times. Subjects were required to complete at least 20 contractions, each 20 second exercise period. This approximated limb velocities of $180° \cdot s^{-1}$. When subjects exceeded 25 contractions in 20 seconds, the resistance setting was increased by one increment. Each training session was monitored by a supervisor who adjusted and recorded resistance settings, numbers of contractions, and precisely timed the work and rest intervals.

During the programme, subjects also trained three times weekly in the water under the supervision of their coach. Two of these sessions were for stroke correction (HR < 150 bpm) and only one was devoted to high quality swimming.

Percent fat was predicted from the six skinfold sites using the methods of Durnin and Womersley (1974) and Pascale (1956).

Maximal oxygen consumption ($\dot{V}O_2$ max) was assessed on a motor-driven treadmill (Quinton 24-72). Subjects ran for one minute on a level treadmill at each of 3.1, 3.6, 4.0, and 4.4 $m \cdot s^{-1}$ and then the grade was increased 2 percent each minute until $\dot{V}O_2$ max was observed, or until volitional exhaustion. To confirm attainment of $\dot{V}O_2$ max, subjects met one or both of the following criteria: a levelling or decrease in $\dot{V}O_2$ with increasing exercise loads; and a respiratory exchange ratio greater than 1.15. The highest $\dot{V}O_2$ value obtained during the exercise was recorded as $\dot{V}O_2$ max.

Expired gases were collected and analyzed each 30 s for volume and, O_2 and CO_2 concentration with a Beckman Metabolic Measurement Chart (Wilmore, 1976), calibrated before and after each test. Heart rate was recorded each minute from a V5 lead electrocardiograph. Knee flexion and extension were selected for testing because they are reported often in the literature and because the Cybex procedure for testing these joint actions is very similar to the training protocol on Hydra-gym.

Peak torques for right and left knee extension and flexion at angular velocities of 30 and $180° \cdot s^{-1}$ were assessed using a Cybex II isokinetic dynamometer system. Subjects were familiarized with the system and the required limb actions. Limb alignment and stabilization procedures were standardized for each test. A minimum of three continuous maximal extensions and flexions were completed. Subjects were verbally encouraged to exert a maximal effort at all times. In all cases, the $180° \cdot s^{-1}$ test was conducted first, with ample recovery time provided before the $30° \cdot s^{-1}$ test. In order to minimize artifactual torques, the first extension and flexion torques from each series were omitted from the results, and an optimal damping setting of two on the Cybex II Chart recorder was used.

Anaerobic power was measured during a 30 s all-out ride on a modified Monark cycle ergometer. The ergometer was fitted with toe-clips and a micro-switch to electronically count pedal revolutions. Optimal saddle height was determined and the subject warmed up on the bicycle for 60 seconds at a power output of 80 W. During the last five seconds of the warm-up phase, the test resistance was set (64 $g \cdot kg^{-1}$). The investigator then signalled the subject to begin pedalling as fast as possible, and simultaneously connected power to the revolution counter for exactly 30 seconds. To ensure a maximal effort, the test was always conducted with the entire group present to provide encouragement. Upon completion of the initial tests, subjects were given an orientation to the Hydra-gym equipment and the training programme.

Pre-exercise blood samples were taken from a forearm vein on the last day of training. At exactly five minutes post-training, a second sample was taken from the opposite arm. These samples were analyzed for lactate concentration according to the method outlined by the Sigma Chemical Company (1981).

Subjects were blocked on initial relative $\dot{V}O_2$ max into two groups designated High Aerobic Power ($\bar{x}$ $\dot{V}O_2$ max = 60.0 $ml \cdot kg^{-1} \cdot min^{-1}$) and Low Aerobic Power($\bar{x}$ $\dot{V}O_2$ max = 52.4 $ml \cdot kg^{-1} \cdot min^{-1}$). This was done for data analysis purposes only. All subjects trained in exactly the same fashion and were unaware of the initial blocking into groups or the primary purpose of the study.

The data were analyzed with independent t-tests, a two-way repeated measures analysis of variance, and post-hoc tests as appropriate.

RESULTS

Adherence to the training programme was essentially the same for both the High and Low Aerobic groups. Due to minor illnesses, one subject from each group missed four training sessions, one from the High Aerobic group missed two sessions, and one from the Low Aerobic group missed three.

TABLE 1

Pretraining Physical Characteristics and Aerobic Power of the High and Low Aerobic Groups

Variable	HIGH (n = 6) Mean ± (S.E.)		LOW (n = 0) Mean ± (S.E.)		2 − tail probability of t
Age (years)	20	(1.3)	17.5	(0.4)	0.065
Height (cm)	176.6	(2.1)	176.9	(2.8)	0.560
Weight (kg)	71.6	(2.0)	72.3	(2.4)	0.834
% Fat	11.2	(0.8)	13.7	(0.7)	0.007
$\dot{V}O_2$max ($l \cdot min^{-1}$)	4.34	(0.11)	3.79	(0.11)	0.005
$\dot{V}O_2$max ($ml \cdot kg^{-1} \cdot min^{-1}$)	60.6	(0.9)	52.4	(0.4)	0.001

A difference ($p < 0.001$) in the relative $\dot{V}O_2$ max was found between the values for the High and the Low Aerobic groups. The High Aerobic group was also found to be leaner ($p < 0.007$) than the Low Aerobic group, but no other differences in physical characteristics were observed (Table I). No changes in weight or percent fat were observed over the training period.

TABLE 2

Peak Torque and 30s Anaerobic Power Output Before and After the Training Programme

Right or Left Knee (R or L) Extension or Flexion (E or F) 30 or $180° \cdot s^{-1}$ (30 or 180)	PRE (n = 12) Mean ± (S.E.)		POST (n = 12) Mean ± (S.E.)		Main - effect ANOVA probability
RE 180 (N · m)	149.8	(4.5)	161.8	(3.9)	0.001
RF 180 (N · m)	112.3	(4.5)	126.7	(4.6)	0.001
LE 180 (N · m)	148.8	(5.1)	163.3	(5.3)	0.001
LF 180 (N · m)	109.0	(5.2)	121.8	(4.7)	0.001
RE 30 (N · m)	248.8	(9.5)	229.?	(9.2)	0.019
RF 30 (N · m)	160.8	(7.2)	168.6	(7.1)	0.128
LE 30 (N · m)	243.9	(9.8)	235.1	(5.7)	0.381
LF 30 (N · m)	157.7	(9.6)	155.9	(6.5)	0.785
Anaerobic Power (W)	601.0	(15.6)	636.8	(17.2)	0.001
Anaerobic Power ($W \cdot kg^{-1}$)	8.4	(0.2)	8.8	(0.2)	0.001

The main effect differences between pre and post-training peak torque and anaerobic power assessments are displayed in Table II. Increases ($p < 0.001$) in all peak torques for knee flexion and extension at $180° \cdot s^{-1}$ were observed after the training programme. Peak torque in right knee extension at $30° \cdot s^{-1}$ declined ($p < 0.02$) while peak torques at the same velocity in right knee flexion, and left knee extension and flexion, did not change. Anaerobic power outputs expressed in both absolute and relative fashions also increased ($p < 0.001$) across the training period.

Peak torque and anaerobic power characteristics of the High and Low Aerobic groups, pre and post-training, are displayed in Table III. No significant main effects between the High and Low Aerobic groups were found on any of the peak torque or power output variables. An interaction effect ($p < 0.009$) between the High and Low Aerobic groups was found on the right knee extension at $180° \cdot s^{-1}$ variable only. Mean peak torque improvement for the Low Aerobic group was 18.3 $N \cdot m$, while mean peak torque improvement for the High Aerobic group was 6.6 $N \cdot m$.

Blood lactate concentrations from samples taken before and after a training session are reported in Table IV. No differences on pre and post-training values were found between the High and Low Aerobic groups.

TABLE 3

Peak Torque and Power Characteristics of High and Low Aerobic Groups

Variable Right or Left Knee (R or L) Extension or Flexion (E or F) 30 or 180° · s^{-1} (30 or 180)	HIGH (n = 6) Means ± (S.E.) Pre	Post	LOW (n = 6) Means ± (S.E.) Pre	Post	Interaction ANOVA Probability
RE 180 (N · m)	152.3 (6.9)	158.9 (6.0)	146.2 (6.2)	164.5 (5.4)	0.009*
RF 180 (N · m)	108.8 (7.3)	126.1 (7.1)	115.9 (5.6)	127.2 (6.6)	0.323
LE 180 (N · m)	150.5 (8.4)	164.5 (9.5)	146.9 (6.4)	162.0 (5.8)	0.866
LF 180 (N · m)	111.9 (9.5)	127.7 (6.9)	106.2 (6.9)	115.7 (5.8)	0.269
RE 30 (N · m)	251.5 (15.2)	245.8 (11.8)	236.2 (11.9)	212.5 (10.9)	0.116
RF 30 (N · m)	160.3 (11.7)	165.2 (8.7)	161.4 (9.5)	171.9 (11.8)	0.561
LE 30 (N · m)	255.6 (16.1)	241.6 (8.9)	230.9 (10.2)	226.8 (6.8)	0.523
LF 30 (N · m)	163.7 (16.8)	159.6 (6.8)	151.6 (10.4)	152.3 (11.7)	0.703
Anaerobic Power (W)	584.7 (16.4)	633.0 (21.4)	617.4 (24.4)	640.7 (26.5)	0.105
Anaerobic Power (W · kg^{-1})	8.2 (0.1)	8.8 (0.2)	8.6 (0.1)	8.9 (0.2)	0.179

*Post-hoc contrast $p < 0.05$

TABLE 4

Blood Lactate Concentrations Before and After a Power Training Session

	HIGH (n = 6) Mean ± (S.E.)		LOW (n = 6) Mean ± (S.E.)		COLLAPSED (n = 12) Mean ± (S.E.)	
LACTATE (mg%) PRETRAINING	11.7	(0.5)	10.2	(1.4)	11.0	(1.1)
LACTATE (mg%) POSTTRAINING	93.9	(1.8)	87.9	(1.4)	90.9	(2.0)

DISCUSSION

Since no change in three of four slow velocity (30° · s^{-1}) peak torques, and a decrease ($p < 0.02$) in the fourth were observed (Table II), these data do not support earlier findings (Pipes and Wilmore, 1976, Caizzo et al., 1980, Lesmes et al., 1978) which showed strength transfer from training at high velocities to performance at low velocities. The change in peak torques for knee extension and flexion at 180° · s^{-1} (Table II) demonstrate that a programme of this type will elicit increases in peak muscular torques measured at or near the training velocity. Thus, specificity of velocity in strength and power training may be more pronouced that was previously thought.

The main effect ($p < 0.001$) in the right knee extension (Table II) was due almost entirely ($p < 0.009$) to the improvement of the Low Aerobic group (Table III). For all other peak torques in knee extension and flexion at 180° · s^{-1}, and for anaerobic power outputs on the bicycle ergometer, there were no differences between the mean improvements of the High and Low Aerobic groups. This indicated that with this subject pool, aerobic power, as measured by $\dot{V}O_2$ max did not appear to be a limiting factor to muscular power acquisition. It is possible that there is some minimum level of aerobic power which facilitates recovery. However, both groups exceeded a possible necessary threshold. Another alternative might be that the work: recovery ratio (1:3) was low enough that all the subjects were able to recover adequately between exercise and, therefore, recovery was not limiting. The similarly high post exercise blood lactates would seem to support this possibility.

In summary, this training programme resulted in positive changes in peak torque in both knee extension and flexion at 180° · s^{-1}, and in anaerobic power outputs. The principle of specificity of velocity in strength was upheld. Initial $\dot{V}O_2$ max did not appear to limit the acquisition of muscular strength and power.

Rec'd. per Cunningham
Acc'd. 20/6/84

ACKNOWLEDGEMENT

Supported by NSERC A-7555

REFERENCES

Caiozzo, V. J., Perine, J. J., Edgerton, V. R., Alterations in the VIVO force-velocity relationship. Med. Sci. Sports Ex., 12:134, 1980 (abstract).

Coyle, E. F., Feiring, D., Muscular power improvements: specificity of training velocity. Med. Sci. Sports Ex., 12:134, 1980 (abstract).

Durnin, J. V., Womersley, J., Body fat assessed from total body density and its estimation from skinfold thicknesses. Br. J. Nutrition, 32:95, 1974.

Lesmes, G. R., Costill, D. L., Coyle, E. F., Fink, W. J., Muscle strength and power changes during maximal isokinetic training. Med. Sci. Sports, 10:226-269, 1978.

Moffroid, M. and Whipple, R. H., Specificity of speed of exercise. Phys. Ther. 50:1693-1699, 1970.

Pascale, L. R. Correlations between thickness of skinfolds and body density in 88 soldiers. Human Biol., 165-176, 1956.

Pipes, T. V., Wilmore, J. H., Isokinetics vs. isotonic strength training in adult men. Med. Sci. Sports, 7:262-274, 1975.

Sale, D. G., MacDougall, J. D., Specificity in strength training: a review for the coach and athlete. Can. J. Appl. Sports Sci., 6:87-92, 1981.

Sigma Chemical Company. The quantitative determination of pyruvic acid and lactic acid. Sigma Technical Bulletin No. 826-UV, June, 1981.

Wenger, H. A., The many faces of aerobic fitness, in Jackson, J. J., and Turkington, H. D. (eds): Quality Programming in H.P.E.R. 55-62 Victoria: University of Victoria, 1981.

Wilmore, J. H., David, J. A., Norton, A. C. An automated system for assessing metabolic and respiratory function during exercise. J. Appl. Physiol., 40:619-624, 1976.