Metabolic reaction after concentric and eccentric endurance-exercise of the knee and ankle

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ABSTRACT

Purpose: Power training plays an essential part in many sport disciplines. The importance of eccentric power training remains a matter of controversial discussion. The objective of this study was therefore to investigate the difference in metabolic reaction between eccentric and concentric stress in comparable work.

Methods: Sixty-four men between 22 and 60 yr of age performed maximum isokinetic 1-min endurance tests of the knee and ankle each in concentric (180°·s⁻¹) and eccentric (60°·s⁻¹) modes with comparable total area of contraction-time curve (NS). Higher strength values (mean peak torque, \(P_{0.01}\)), lower fatigue (fatigue index, \(P_{0.001}\)), lower increase in lactate (\(P_{0.01}\)), and lower ammonia production (\(P_{0.01}\)) were found in eccentric than in concentric exercise, independent of the joint. The eccentric form of stress showed lower decrease and thus age-dependence in maximum strength and in fatigue than the concentric form. Results: The results permit the conclusion that eccentric exercise leads to less fatigue and lower lactate and ammonia reaction than concentric exercise in comparable work levels. Variable visco-elastic properties of the muscle fibers themselves with additive passive strength in eccentric mode is considered as the cause. Conclusions: It remains uncertain whether the lower metabolic stress might be useful during the training process. A greater scope of training and increased number of training stimuli might be applied in primarily eccentric forms of exercise. Key Words: LACTATE, AMMONIA, MUSCULAR FATIGUE

Power training is an essential component in the training regiment of various types of sports. The importance of eccentric forms of strength training are a matter of controversial discussion. Usually higher strength values are attained in eccentric forms of exercise than in concentric and isometric forms (25). By contrast, a lower electromyo-graphic activation has been demonstrated at comparable strength performance in the eccentric mode (14,25). These greater strengths are explained in part by variable visco-elastic properties of the muscle fibers themselves resulting from stretching of the serial-elastic elements (11). Little is known as yet concerning the metabolic reaction to the various working modes, and the few statements published in the literature on lactate production are contradictory (2,3,8,14,15). No studies have yet been published on ammonia production as a criteria of anaerobic-alactacid metabolism (19) under isokinetic stress. However, essential evidence of the degree of stress in the exercised muscle are to be expected from the metabolic reaction.

The goal of this study was therefore to examine the metabolic reaction of lactate and ammonium in eccentric and concentric endurance exercise at comparable overall performance. The query was addressed to large and small muscle groups separately by age.

METHODS

Subjects
Sixty-four male subjects between 22 and 60 yr of age participated in the study (38.7 ± 12.5 yr, 178 ± 7.4 cm, and 74.9 ± 8.7 kg). Cardiovascular disease was ruled out in all subjects on the basis of the individual history and physical examination. The subjects were to be free of complaints in the dominant leg and fully capable of exercise. Persons engaging in physical exercise more than 2 h or MET level > 2.0 per week were excluded. All subjects were informed about the nature, scope, and risks of the study and granted written consent to participation.

Isokinetic measurements. The isokinetic measurements were performed using a LIDO ACTIVE dynamometer (Loredan Biomedical Inc., Davis, CA). This equipment permits both concentric and eccentric forms of exercise. Presentation, storage, and calculation of the measured values was made using an IBM-compatible 486-DX PC. In preparation, a 5-min warm-up phase was performed on a bicycle ergometer at a level of 1.5 W·kg⁻¹ body weight at 60 rpm, followed by a 10-min stretch phase of the lower extremities.

On day 1, the knee was tested. The subject took a sitting position, and a belt was placed across hips and chest. The
dominant leg was also restrained with a padded cushion, and the range of movement set from 90° to 0°. The subject was given the possibility of becoming accustomed to each angle acceleration before each series with 2 submaximal repetitions. First a maximum 1-min concentric endurance stress was performed at 180°·s⁻¹. A minimum15-min pause followed, consisting of 5-min relaxed bicycle pedaling, 5-min stretching, and 5-min sitting. The eccentric series was performed at 60°·s⁻¹ in the same form as the concentric measurement. After pretrials, this form of exercise was selected to achieve comparable overall performance during the 1-min exercise form.

The ankle measurements followed 5 d later, likewise at 180°·s⁻¹ in concentric mode and 60°·s⁻¹ in the eccentric mode. The subject was then laying on his back and fixed over the chest and femur. The sum of the maximum torque of extension and flexion was determined from the strength curves. Average peak torque and total work were calculated as follows: (mean of the 3 maximum torque curves within the initial 5 contractions + mean of the last 5 contractions) divided by 2. The figures for extension and flexion were then added. For the fatigue index (FI), the mean of the last 5 contractions was divided by the mean of the 3 maximum torques within the initial 5 contractions which was set as 100%.

**Biochemical assays.** Blood samples for the determination of lactate were taken from hyperemic ear lobe before and directly, 3 and 5 min after exercise. Measurements were performed by means of an ESAT 6661 (Eppendorf, Germany).

Venous blood for ammonia determination was collected out of a i.v. indwelling cannula (Vialon INSYTE 22G, San Augustin, Spain) before, directly at, and 3 min after exercise. It was carefully stored in an EDTE-di-potassium sample container for protection against hemolysis. Analysis of 20-μL blood, drawn with a variopipette (Eppendorf, Germany), was made immediately using an ammonia-checker II, model AA 4120 (Kyoto Daiichi Kagatu, Japan).

**Statistical Procedures**

Differences in the mean were checked by the unpaired Student’s t-test with the significance levels NS = not significant, \( P < 0.05 \) (*), \( P < 0.01 \) (**), and \( P < 0.001 \) (***) . Individual parameters were checked for age-dependence using linear correlation calculation with \( P < 0.01 \) = significant. Statistical calculations were made using the software package STATGRAPHICS, Version 5, 1991, from STCS, Inc., Rockville, MD.

**RESULTS**

**Isokinetic Measurements**

**Average peak torque.** The highest values were measured in eccentric form of exercise in the knee (mean 320 Nm) compared with the concentric values (167 Nm; \( P < 0.001 \); Fig. 1). The relationship of flexion to extension was not different in the two modi (NS). The eccentric strength (167 Nm) and the concentric strength (57 Nm) in the ankle were considerably lower. Here, too, the relationship of flexion to extension was nearly identical in both modi (NS). In a comparison of the joints, the concentric strength values in the knee were triple those in the ankle, whereas the values of eccentric exercise were only twice as high. The upper thigh musculature attains on the average values in the eccentric mode which were double those in concentric mode, and the calf musculature attained three times the strength in eccentric as in the concentric mode. The mean strength values for flexion and extension combined showed a negative correlation to the age of the subject. (\( r = -0.52, P < 0.001 \); Fig. 2).

**Total work.** In the concentric exercise form, there was a mean contraction rate of 40-min⁻¹ and in the eccentric mode of 17-min⁻¹ for the knee, 67-min⁻¹, and 40-min⁻¹ for the ankle joint, respectively. Due to the higher maximum work in the eccentric mode (384 J/repetition vs 156 J/repetition), there was no difference in total work during an exercise time of 1 min between concentric (6240 J) and eccentric forms (6528 J).
J) of exercise for the knee (NS). For the ankle joint, the work per repetition was 48 J and 93 J in concentric and eccentric mode; no difference occurred in total work (3216 J and 3720 J, NS).

**Fatigue index.** The FI showed clearly lower values in concentric exercise compared with eccentric exercise in both joints \((P < 0.001; \text{Fig. 3})\). There was no difference between flexion and extension in the knee (NS); in the ankle, the FI for dorsiflexion was 26\% below that of plantarflexion \((P < 0.01)\). In the eccentric mode, the greatest fatigue was seen in dorsiflexion. The least concentric fatigue was found in plantarflexion, which means that the FI for concentric and eccentric differs least (quotient eccentric/concentric 1.47 ± 0.48). The greatest difference was found in dorsiflexion \((2.32 ± 0.98)\), followed by knee extensors and flexors with 1.83 ± 0.48 and 1.65 ± 0.40.

With age, the FI in the concentric forms of exercise in the knee joint showed a slight increase (lower fatigue) between 8 and 16\%, in eccentric forms between 2 and 8\%. In the ankle musculature, pronounced fatigue between 13 and 30\% was seen in the concentric mode, and between 0 and 10\% in the eccentric mode.

**Biochemical Measurements**

**Lactate.** The metabolic reaction for lactate in the individual muscle groups is shown in Figure 4 as the difference from baseline to maximum value. The lactate concentrations increased in all exercises to a highly significant degree above the resting value. At the same time, the increase was significantly higher in all concentric exercises than in the eccentric exercises. The thigh musculature in the concentric mode reached more than the four-fold; the ankle musculature tripled the values compared with the eccentric mode.

Starting with a resting value of 2.0–2.2 mmol·L\(^{-1}\), the increase in the concentric for the knee joint reached nearly double that of the ankle, in the eccentric the low increases were of the same magnitude. The maximum increases after concentric exercise occurred in the knee joint in 39\% of the subjects after 3 min and in 56\% after 5 min. In the ankle, the distribution is 70\% to 23\%. After eccentric exercise, the maxima for both joints were found in 33\% immediately, 3 min, and 5 min after the end of exercise.

The correlations between lactate differences and the FI showed a significant relationship only for the knee. For flexion in the concentric mode \((r = -0.41, P < 0.001)\), no significant relationships were observed for any other forms of exercise.

**Ammonia.** The behavior of the ammonia concentrations before and after exercise were comparable to the lactate concentrations (Fig. 5). For the knee extension in concentric mode, there was a correlation to the FI of \(r = -0.29 (P < 0.05)\), for the knee flexion of \(r = -0.35 (P < 0.01)\). There was no significant relationship for the eccentric forms of exercise in the knee or any ankle exercises.

Between lactate and ammonia values in the concentric mode, there was a correlation of \(r = 0.58\) for the knee and \(r = 0.55\) for the ankle \((P < 0.001)\). In the eccentric mode, the values were not significant.

**DISCUSSION**

In many sports disciplines general and sport-specific strength training or strength-endurance training plays an important role. The effect of training depends in part from the tension attained and the number of times the stress is repeated. From this point of view, eccentric forms of exercise are interesting, because usually greater strength and tension values are attained than in concentric or isometric
forms. It is unclear whether this is accompanied by elevated metabolic stress to the exercised musculature.

To investigate this, the total work performed in concentric and eccentric exercise mode were kept comparable by selecting a higher angular velocity for the concentric mode. This did increase the difference in average torque between the eccentric and concentric exercise somewhat, but the main difference is most likely due to an elementary characteristic, seen as variable visco-elastic properties of the muscle fiber. This assumption is supported by evidence of lower neuromuscular activity in spite of greater strength development in the eccentric mode than in concentric forms of exercise (14,25). The findings reported by Aratow et al. (1) in the musculus soleus and musculus tibialis anterior may also be interpreted in this way, in which further eccentric tension development was demonstrated in spite of maximum nerve innervation. This difference can be seen in this study in both the knee joint and ankle, even though the difference in the knee was somewhat lower than in the ankle. Apparently, the thigh musculature attains a somewhat higher proportion of maximum strength than the calf musculature at the selected angular velocity in the concentric mode (180°-s⁻¹).

The known decrease in maximum strength was observed during concentric endurance exercise over 1 min (4,13,16,20,21,22). The values for extension are somewhat higher and of the same magnitude for flexion (9). Although greater fatigue is found in isometric and concentric exercise in endurance exercise, the higher the maximum applicable strength is (7), the lower fatigue is as described by Gray and Chandler (10) and by Verdonck et al. (24) in eccentric than concentric endurance exercise. This agrees with the data we recorded, which demonstrated lower fatigue (higher FI) in eccentric forms of exercise.

The metabolic reaction findings support the assumption that the factors which result in muscular fatigue in concentric exercise play a lesser role in eccentric endurance exercise (22). Considerably greater increases are observed in both lactate production and ammonium production in the concentric mode than in the eccentric mode. The behavior of the metabolic reaction is joint-independent and differs only in the absolute values due to lower muscle mass used in the ankle. The mean contraction rate in the concentric mode of about 40 movements-min⁻¹ for the knee and 67 for the ankle is about twice as great as in the eccentric mode (17-min⁻¹ and 40-min⁻¹), but the strengths and tensions attained in the eccentric mode are much higher and should theoretically lead to greater metabolic answer of lactate and ammonia than the concentric exercise.

Our results thus agree with the findings of Bonde-Petersen et al. (3) and Knuttgen (14), who also demonstrated very low lactate values after eccentric stress compared with concentric forms of exercise. Earlier studies did not find this difference, but no comparative methodology was applied (15).

The ammonia reaction was qualitatively comparable to lactate. Because the purine-nuclide cycle is greater in FT fibers than in ST fibers (6,12,23), and thus affected by higher strength and tension stresses, this may be taken as further evidence that there is a basically different form of stress between concentric and eccentric exercise (17,18). This is also supported by a correlation between the increases in the metabolites lactate and ammonia to fatigue which can only be established in concentric forms of exercise, a finding that agrees with the report by Douris (5).

The present study thus generally supports the assumption that the elevated strength and tension values at comparable work level in the eccentric mode result in lower metabolic stress than in the concentric mode. This agrees with the supposition that these greater strengths and tensions are located in the actin-myosin structure via additive, passive elastic strengths at the molecular level. It remains uncertain whether the lower metabolic stress might be useful during the training process. A greater scope of training and increased number of training stimuli might be applied in primarily eccentric forms of exercise. Additional training studies are needed for substantiation of this hypothesis relevant for training practice.

REFERENCES


10. GRAY, J. C., and J. M. CHANDLER. Percent decline in peak torque production during repeated concentric and eccentric contractions.


