THE EFFECT OF DIFFERENT LOAD INTENSITIES ON THE DEVELOPMENT OF MAXIMAL STRENGTH AND STRENGTH ENDURANCE

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To date, the understanding of strength training is still surprisingly underdeveloped. In this article, Pampus, Lehnertz and Martin discuss the results from their research on the effect different loading patterns have on the important qualities of maximal strength and strength endurance, and relationships between these two strength qualities. Reprinted with permission from Modern Athlete and Coach.

INTRODUCTION

The problem of the load distribution and the effectiveness of stimuli within the training process have not yet been satisfactorily solved. This is also true to strength training. There is still not sufficient different analysis available on the various strength training methods and their specific effects. This was stressed by Lehnertz (1985), who wrote: "While we are well informed about the aims and the strength capacities, the scientific knowledge on the effectiveness and contents of training methods is strongly underdeveloped". The question of an optimal stimulus for the development of strength is here particularly unanswered.

The following three guidelines have been mentioned for the achievement of improved performances:

1. The creation of fatigue through a large training volume. This means employing a relatively large number of repetitions in which the percentage from the maximal strength is characteristic for intensity (25 to 75 %).

2. Short recoveries (60 to 90 seconds) in order to avoid full regeneration (energy situation).

3. A high movement speed in which a full load takes place only when each exercise is executed close to maximal speed (Lehnertz 1986, Kunz/Unold 1986).

A quick look at the literature shows immediately differences in the application of optimal intensities. Letzleter (1986), for example, recommends 40 to 60% in the so called extensive interval method.

Kunz/Unold (1986), on the other hand, considers 30 to 50% as suitable and Thies et al. regard 75% intensity as efficient when the number of repetitions in a set covers a range from 8 to 60 total repetitions. Weineck (1980) suggests in this context that strength endurance performances above 50% from the maximal strength require a number of repetitions that depend on the level of maximal strength. This additional aspect indicates that an improvement of maximal strength will lead to better strength endurance capacity.

Divided views also exist on the second component of intensity, the movement speed. An explosive execution is here generally recommended in order to stimulate the fast, but rapidly fatigued, muscle fibres. Kunz/Unold (1986) reported, in contrast, that strength endurance also can be developed by employing dynamically slow strength training. In order to establish a better base for the determination of load intensities we conducted a study into the effectiveness of various load intensities on the development of strength endurance.

THE MUSCLE PERFORMANCE THRESHOLD AS AN INDICATOR OF THE MUSCULAR WORK CAPACITY

In our project we approached the determination of intensity from the state individual muscular performance. Contrary to the usual procedures, our judgment of the performance was not based on the level of maximal strength, nor the number of repetitions, but on maximal mechanical muscle performance. The following text presents the first part of the study results.

Our study of the strength qualities was orientated to the maximal muscular performance. This means that strength training took into consideration the state individual muscular performance. This state was based on the muscular performance threshold (MLS). The MLS occurred at a point when skeletal muscles worked within a relative maximum of energy transfer (Lehnertz/Pampus 1988). This parameter appears to represent exceptionally well the strength level of an athlete. We were able to establish high correlations between MLS and maximal isometric strength (r = 0.92), as well as MLS and maximal kinetic energy (r = 0.96) as indicators of power.

The calculation of the maximal muscular performance and with it the maximal energy transfer is based on the studies by Hill (1938) in isolated frog muscles. The validity of this for human muscles has been shown by Ralston et al. (1949) and Wilkie (1950). It has been shown that the highest possible performance is achieved when the maximal possible speed is shortened by about one third against the resistance of a weight about one third of the maximal strength.

The impulse of the accelerated mass (kg x m/s) serves as the indicator of muscular performance. The weight responsible for the largest impulse (maximal performance) is denoted by us as the threshold weight. A maximal performance can only be developed when: firstly, all muscles working in the direction of the movement are activated and, secondly, the muscular work against the mass occurs in the shortest possible time. Provided we accept that in this case the energy turnover is maximal and the corresponding physiological and biochemical adaptation processes occur, then the MLS appears to be in the range to train particularly well all strength qualities.

The concept of MLS is presented in Figure 1. It shows the performance diagram of two subjects of different performance capacities in the so called bench pulls (Figure 2). This test procedure, as well studies of strength endurance and maximal strength, will be described and substantiated.

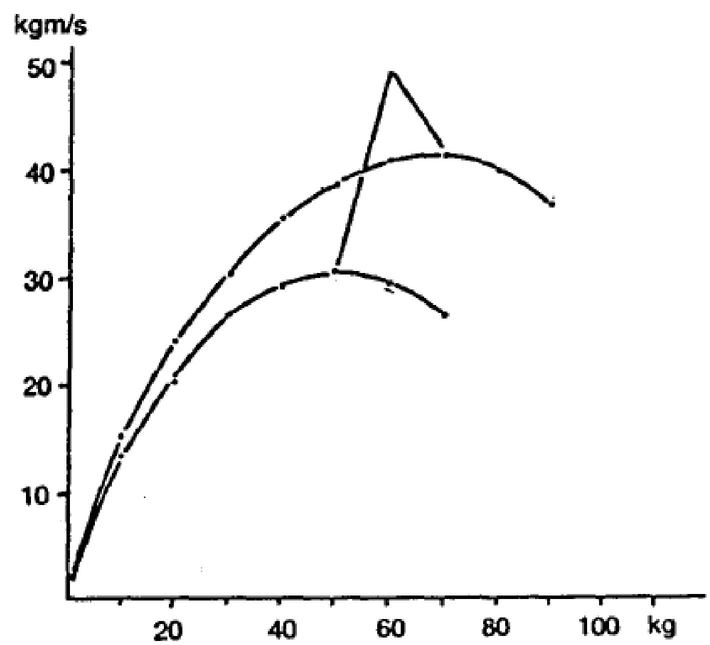

FIG. 1: Muscle performance curves of 2 subjects with a performance maximum (MLS) at a threshold weight of 50 and 70kg respectively.

DESCRIPTION OF THE STUDY

The main study, conducted in winter 1987/88, followed a pretest involving 24 male and female subjects (Lehnertz/Pampus 1988). The subjects for the main study were 42 junior male oarsmen (born between 1969 and 1972) from local schools. The oarsmen had taken part in rowing more than three years (x = 48 months), during which they trained several times a week, including regular strength training in transition periods. Their good performance level is reflected by successful performances of some boats in competitions. The group can be considered to have test experience, as they had been regularly tested by the coaches.

Substantiation of the Test Exercise

Tests should be:

- As close as possible sport specific.
- Using simple movements, free of learning effects, for the determination of motor capacities.
- Easy to standardize.

These conditions were achieved for rowing in the bench pull. The bench pull has for years been an exercise used by our study subjects in strength training, as well as for tests to determine maximal strength and strength endurance. According to Letzelter/Letzelter (1986) the bench pull has the criteria to determine the maximal strength, strength endurance and power of the arms.

Description of the Test Procedures

The subject is in a prone position on a bench and pulls from the ground a barbell vertically upward. The bench is adjustable in height for an individual starting position so that the exercise begins with straight arms (180° elbow joint). The weight is pulled with an all-out effort as fast as possible to the lower surface of the bench. The speed of the pulling performance is measured with an infrared light beam. The movement time is determined in microseconds from 0 to 3.5cm, for 0 to 15cm and 0 to 30cm.

Progressively increased weights (by 10kg) are used in six attempts for each weight to establish the muscle performance threshold from the median values of the load impulses (= mass x velocity).

Recovery periods of two to three minutes in the MLS range, and slightly shorter for lower weights, are used between single attempts in order to establish the fastest possible times. The MLS was in this study determined by the achieved times over the first 3.5cm. This appeared to us suitable for the following reasons:

- The strength of the contractile component of skeletal muscles is the largest when the myofilaments have the maximal overlapping. This is the range of the resting length (L_0) of the muscle. According to Hasselbach (1975) the maximal possible tension is reached between 90 to 110% of the resting length.

In our study the "initial" elbow angle was 180º at the start of the pull. As this stretched the initial angle a little over L_0, the starting phase of the test movement provided the required conditions for a maximal strength development.

- It is noticeable in the comparison of isometric and concentric strength-time curves that they follow a similar format in the maximal contraction range (Schmidtbleicher 1984, Buhrle 1985). The speed of the strength increase takes a virtually linear path shortly after the start of the movement. This allows us to accept that the average speed over this short distance gives exact information on the contraction speed.

- Individually different length of the extremities have in this measuring range no significant influence on the joint angles or the length of the muscles. This provides mechanical advantages for standardized performance conditions.

Maximal Isometric Strength

The starting position is the same as in the determination of the muscular performance threshold. The subject again pulls with completely stretched arms on a metal strength measuring plate. The strength values are recorded by a personal computer.

Strength Endurance

The test procedure is similar to the muscular performance threshold test. In order to determine strength endurance, the subject pulls the barbell in a 2.5 second rhythm. The load corresponds to 60% of the threshold weight. The criteria for strength endurance is calculated from the total work performed (the number of pulls x load). The test is broken up when the subject fails to keep up with the acoustical signals of the rhythm or the load does in two following pulls miss the minimum of a 30cm path. The last can be exactly registered by the top light beam.

The Conduct of the Study

The oarsmen were divided into three homogeneous groups based on their maximal isometric strength. The following groups were formed:

Training group I
(TG I), n = 16

Training group II
(TG II), n = 12

Control group
(KG), n = 13

Training Methods

Both groups, based on the information obtained from the determination of muscle performance threshold, trained as shown in table 1.

	LOAD LEVEL	SETS	REPS	LENGTH OF RECOVERIES	MOVEMENT TEMPO
TG I	Individual threshold weight (= 100%)	4	9	10 sec. between reps, 5 min. between sets	— explosive, fast — (maximal)
TG II	60% of individual threshold weight	4	15	5 min. between sets	— unchanged tempo — slow, continuing

TABLE 1: Testing procedures for the two training groups.

TG I, training in the MLS range, worked exclusively concentrically. One set lasted 80 seconds with 0.4 to 0.6 seconds between each pulling movement. TG II worked concentrically and eccentrically with an unchanged muscular tension in a slow cyclic fashion. It resembled isokinetic work. The average load duration was 107 seconds.

Control group (KG): A part of the KG group trained during the study only occasionally, or not as all.

The physical work, based on the total volume of the load, was kept even for both methods in order to provide a comparison of their effectiveness (For example: TG I - 9 repetitions at 100% = 900% corresponds to TG II - 15 repetitions at 60% = 900%). Only the bench pull exercise was used in this study because this exercise also doubled as the test. The study duration extended from the beginning of October to the end of December. Strength training over the 10 weeks was conducted three times a week (Sundays, Wednesdays, and Fridays). Pre and post-study test took place to establish: muscle strength threshold, maximal strength, strength endurance.

Presumed Training Effects

Emphasis on both load intensities should have been on the training effect of strength endurance. We presumed thereby an improvement in the level of maximal strength, as well as strength endurance. The use of both intensities was expected to differentiate their effect of strength endurance. Our hypotheses were:

1. Both load intensities lead to an improvement of maximal strength.

2. Both load intensities lead to an improvement of strength endurance.

3. Training with quasi-isokinetic load structure will contribute more to the improvement of strength endurance than training within the range of the muscle performance threshold.

RESULTS

The median values with standard deviations for the three study groups in both tests and their differences are shown in table 2.

		TG I x	n = 16 SD	TG II x	n = 12 SD	KG x	n = 13 SD
Maximal	VT	1807.8	223.7	1845.1	238	1800.8	326.4
Isometric Strength (N)	NT	2396.6	337.9	2343.2	344.9	2039.7	373.6
Strength Endurance	VT	44.6	16.9	44.3	13.9	39	10.4
(Number of Pulls)	NT	62.2	22.9	70.9	18.9	39.1	8.9
Differences		abs.	%	abs.	%	abs.	%
Maximal Isometric Strength (N)		581.8	32.2	498.1	27	238.9	13.3
Number of Pulls		17.6	39.4	26.6	60	0.1	0.2

TABLE 2: Median values and standard deviations in maximal strength and strength endurance of the three groups in pre- and post-tests (VT/NT) with absolute and relative improvements.

The median values of maximal isometric strength, as well as strength endurance in the pre and post-study tests are presented in Figure 4 and Figure 5.

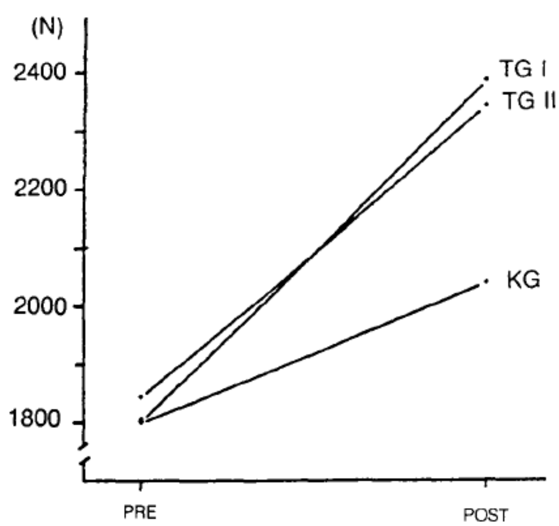

FIG. 4: Median values and standard deviations in maximal isometric strength (pre and post-tests)

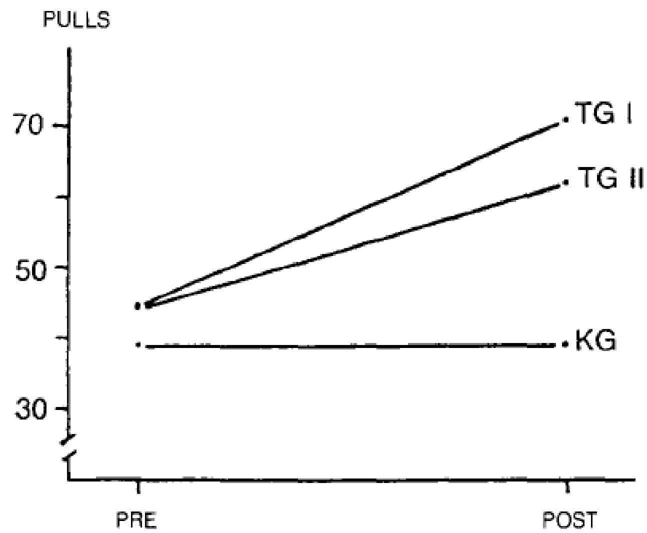

FIG. 5: Median values of the pulls in strength endurance test (pre and post-tests)

Both load intensities have been significantly responsible for the improvement of muscular strength. Training group I improved by 581.8 Newton's (32.2%), training group II by 498.1 Newton's (27%). Even the control group showed in 13.3% significantly improved maximal strength (Table 2).

The improvement of strength endurance in both training groups also is significant. Training group II achieved a 60% improvement, over 20% more than training group I (39.4% improvement). There was practically no improvement in the control group (0.2%).

DISCUSSION

Development of Isometric Strength

The first hypothesis can be accepted on the results of very significant improvement of maximal strength. The significant improvement of the control group could have been the result of individually conducted strength training by some subjects. Growth stipulated performance improvement at this age range also can't be completely excluded. This applies naturally to both training groups. Taking into consideration the remaining difference by subtracting 13.3%, leaves the actual training effect 18.9% for group I and 13.7% for group II. The physiological reasons for the improvement of maximal strength requires the understanding of two adaptation mechanisms. The arbitrarily applicable maximal strength can be improved:

1. By increasing the cross section of a muscle (hypertrophy).

2. By improving the arbitrary activation capacity (reduction of strength deficits).

The term "strength deficit" expresses the relationship between the possible strength development of morphologically determined fibre structure and the actually activated strength. The strength deficit, according to Letzelter/Letzelter (1986), varies between 30% in untrained and 10% in trained persons.

The growth of the muscle fibre thickness is at this time not unequivocally clear. Next to the hypothesis that it occurs through the influence of microtraumas, created by the high tension in muscles or on the protein synthesis, is the opinion that anaerobic glycolytic working manner is responsible. The reason is in the lowering of pH values that, among other, is reflected in the production of lactate.

According to Hollmann/Hettinger (1980) it is necessary to exceed the critical tension threshold to produce stimulus for hypertrophy.

The training of our group I can be classified as the method referred to in the literature as coordination training (lK) for the reduction of strength deficit (Kunz/Unold 1986, Buhrle 1985, Simkin 1960, Zaciorskij 1972). This is not supposed to increase the cross section because the muscles are activated only for a short time.

The training method of group II, because of the characteristically slow and continuing concentric and eccentric movement structure, is referred to as the isokinetic method (Buhrle 1985). It has similarity with the body building methods and leads over an increased cross section of a muscle to increased muscular strength.

The improved maximal strength in the method IK is substantiated by the activation of all motor units, particularly the fast twitch fibres, reacting to the high stimulus threshold. This results in the contraction of more muscle fibres per time unit that leads to a reduction of the strength deficit. This effect must be accepted for the significant improvement of maximal strength in group I that showed a "net" increase of 18.9%, corresponding to the percentage limits (110 to 130%) claimed for the reduction of the strength deficit through IK training by Letzelter/Letzelter.

According to Buhrle (1985) there is very little difference between the hypertrophy training for the reduction of the strength deficit and the IK method, provided the strength insertion is about the same. Buhrle defines the IK method as load level 100%, 5 sets of one repetition each and the muscle cross section method as load level 80%, 3 sets of 8 to 10 repetitions (standard method I). Compared to Buhrle's recommended 3-minute recoveries between the single contractions the 10 second recoveries employed by our training group are very limited. This, in our nine-repetition sets, should have made it possible to increase hypertrophy.

Fukunaga (1976) conducted a two-month study in connection with this problem. He discovered in the laboratory experiment that the maximal strength of arm muscles increased strongly in the first three weeks without an increase of the muscle cross-section through improved coordination. Only after that followed an essentially limited strength increase through hypertrophy.

On the other hand, it also is possible that the pulling of heavy loads was responsible for large muscle tension, so that hypertrophy occurred because of microtraumas in the muscle fibre. We therefore have the opinion that additional hypertrophy could have occurred next to the typical effect of the IK method. We decided to conduct a biochemical examination to eliminate, or at least reduce, the doubt about the influence of hypertrophy creating mechanisms on maximal strength and strength endurance in both training groups. This will be discussed later in the text.

Development of Strength Endurance

Training group II achieved a very significant 60% improvement in strength endurance. This was 20% higher than the 39.4% improvement in training group I (table 2). It makes the second hypothesis acceptable. An exchange effect, however, is not evident, as there is in the third hypothesis no statistically significant correlation, although a 20% difference was acceptable. The reason for this are the widely distributed values (table 2) within both training groups in the highly motivation dependent test of strength endurance. The same can probably explain the extraordinary fact that the control group showed no improvement in strength endurance. According to the shown correlation between maximal strength and strength endurance performance against high resistances (> 50%), an improvement in strength endurance can be expected when maximal strength increases. It appears possible that the subjects in the control group were simply not prepared to produce another demanding and trying performance.

The distinct improvement of training group II has the following reasons: The dynamically slow training of group II with a movement speed of approximately 0.2m/sec forces the muscle through a large number of repetitions and sufficiently high muscular tension of 60% of the threshold weight during the onset of fatigue to recruit more motor units in order to compensate for the loss of muscle tension. It should be noted here that additional motor units are switched on already during the concentric phase, as the bending angle becomes smaller in order to produce force against the weight load. Consequently, even in this method, each fibre is dependent on the contraction stimulus. This stimulus strongly reduces during the exercise glycogen reserves and is, according to Kunz/Unold, responsible besides maximal strength, also for strength endurance.

The training load of group I can be looked at as being anaerobic alactic work because the muscle produces explosive and short duration (0.4 to 0.6 sec.)

single contractions with 10 second recoveries. It is interesting to note that these short, explosive contractions can be responsible for a clear improvement in strength endurance performances.

This brings up the question of whether the anaerobic glycolytic adaptation system could have been involved in the muscle performance threshold training through the accumulation of fatigue. This possibility was examined in a post study with lactate measurements. The procedures of the study are shortly explained below.

THE POST STUDY

Nine subjects from each of the two training groups performed once again a training unit with the same load structure as during the previous training period (table 1). The lactate level at rest and the initial lactate before and after a standardized warm-up were established. This was followed by the four sets of the exercise with lactate measurements taken after 30 and 120 seconds in the five minute recovery between the sets and at the end of the load in each set.

The differences between the two groups and the changes in the highest values within each set are in 1 percent level statistically significant. The Wilcoxon test shows significant lactate increases after the warm-up (+ + = 1 percent and + = 0.5 percent) for both training groups. This continues for training group II until the end of the first set and remains high at 5.5mmol/llevel until the end of the training unit. The lactate accumulated during the warm-up of training group I (4.71 mmol/l) is gradually reduced to a final lactate level of 2.41 mmol/l (initial value 1.87mmol/l).

These lactate changes confirm our assumptions:

1. The 10-second recoveries (TG I) are sufficient to accomplish ATP resynthesis, while no statement can be made on the creative phosphate level that occurs through oxidative or glycolytic conversion. The energy provision is anaerobic alactic, shown in the lactate elimination from 4.71 to 2.41 mmol/l during the exercise sets.

2. This indicates the possibility that increased maximal strength and strength endurance in training group I took place through hypertrophy caused by microtraumas, as well as an improved activation capacity. The result is in a larger muscular potential and with it a higher contraction force that reduces the load on single muscle fibres. The exhaustion of their anaerobic capacity takes place slower, making longer contractions of the total muscles possible.

3. Strength training performed with slow movements makes large demands on glycolytic energy provision of the carbohydrate metabolism and

therefore requires an improved anaerobic capacity. This is confirmed by the lactate values that exceeded the anaerobic threshold (about 4mmol/l) during the sets.

A comparison of the two study methods indicates that there is the probability of a better development of strength endurance when the exercise is performed dynamically slow with no recoveries between repetitions. The continuous "muscle pressure" in slow movements is responsible for a reduced blood flow and with it a shortage of oxygen, which reduces lactate elimination. It appears to be the more effective method of the two studied alternatives, as far as an improvement of strength endurance is concerned.

The results of the study confirmed some of the effects of different load intensities mentioned in literature. This allows us to present the following methodical consequences for training:

The training method with continuous slow movement performance in a quasi isokinetic work with load resistances of 60% from the maximal muscle performance can be strongly recommended for a parallel development of maximal strength and strength endurance.

However, our method cannot be regarded as the most effective for the development of strength endurance, because our study provides no comparison to other specific strength endurance development methods.

Training within the muscle performance threshold range can be recommended when the aim is to improve maximal strength through a reduction of the strength deficit between the arbitrary and total muscle fibre potential without infringement of the dynamics or kinetics of the movement execution.