# Effects of Eccentric Strength Training on Different Maximal Strength and Speed-Strength Parameters of the Lower Extremity

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[1]*Department of Human Movement Science and Athletic Training, Institute of Sport Science, Johann Wolfgang Goethe-University, Frankfurt, Germany;* [2]*Swimming Federation of the State Niedersachsen, Hannover, Germany; and* [3]*German Luge and Bobsled Federation*

## Abstract

Wirth, K, Keiner, M, Szilvas, E, Hartmann, H, and Sander, A. Effects of eccentric strength training on different maximal strength and speed-strength parameters of the lower extremity. *J Strength Cond Res* 29(7): 1837–1845, 2015—The aim of this investigation was to analyze the effects of an eccentric strength training protocol using supramaximal loads (>1 repetition maximum [1RM]) on different maximal and explosive strength parameters of the lower extremity. The eccentric maximal strength (EX max), maximal isometric strength ("maximal voluntary contraction" [MVC]), 1RM, explosive strength ("rate of force development" [RFD]), countermovement jump, and squat jump height were tested before and after a training period of 6 weeks. The training group was composed of 15 individuals with low-weight training experience and a control group of 13 subjects, also with a low-weight training experience. The lower extremities were trained 3 days per week using a 45° leg press. Each training session comprised 5 sets of 3 repetitions with a 6-minute rest between each set. The training weights were adjusted continuously during each training session and between training sessions. In each case, a load was chosen that could be lowered unilaterally in a controlled manner by the subjects. For the concentric part of the exercise, 2 investigators lifted the weight to the starting position. After 6 weeks, strength training with supramaximal loads showed a significant increase in EX max (28.2%, $p < 0.001$) and 1RM (31.1%, $p < 0.001$). The increases observed in the control group were not significant. Changes in MVC, RFD, and vertical jump heights were not significant in both groups. The results of this study suggest that in untrained subjects, unilateral eccentric strength training in the leg press generates equal and significant improvements in unilateral eccentric and bilateral eccentric-concentric maximal strength, with a nonsignificant transfer to vertical jump performances and unilateral isometric force production.

**Key Words** eccentric training, specific adaptations, jump performance

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## Introduction

A variety of studies over several decades have examined the effects of strength training using eccentric protocols. The majority of studies have investigated the function of the neuromuscular system during eccentric contractions compared with concentric and isometric contractions. In the last 10 years, interest in eccentric contractions regarding prevention and rehabilitation has increased (9,28,36). The focus of interest of these studies was primarily the treatment of tendonitis and determination of force ratios (agonist-antagonist) (4,9,27–29,35,36,39,44,46,52,60,62,65,69). For example, Askling et al. (9) discuss the positive effects of eccentric strength training on the incidence of injuries in the area of the hamstrings in soccer players, or Jönhagen et al. (28) discuss deficits in the eccentric force development responsible for hamstring injuries in sprinters. Most resistance training studies have focused on the changes induced in different maximum strength parameters and on biochemical data (Table 1).

On the one hand, higher strength performance during eccentric muscle actions is referred to as muscle elasticity, an elongation of the series and parallel elastic component of the muscle; however, on the other hand, this is referred to as an increased reflex activity (stretch reflex), which is triggered by the muscle spindle. Both Pousson et al. (52) and Cornu et al. (12) showed an increase in the stiffness of the series elastic component after eccentric and reactive strength training. Eccentric strength training using supramaximal loads generates primarily neural adaptations (short-time training interventions); however, some authors emphasize the importance of eccentric muscle actions (submaximal) in strength training

**Table 1.** Changes in the maximum force of different parameters after pure strength training using eccentric protocols.†

| Investigation | EX max | KONZ max | 1RM | MIF |
|---|---|---|---|---|
| Komi and Buskirk (31) | * | * | - | - |
| Johnson et al. (26) | - | - | * | (*) |
| Duncan et al. (16) | * | ns | - | - |
| Hortobagyi et al. (22) | * | * | - | * |
| Hortobagyi et al. (24) | * | ns | - | * |
| Seger et al. (57) | * | (*) | - | ns |
| Hawkins et al. (20) | * | (*) | - | - |
| Mouraux et al. (42) | * | * | - | - |
| Paddon-Jones et al. (48) | * | (*) | - | - |
| Nosaka and Newton (45) | * | * | - | - |
| Schroeder et al. (56) | - | - | * | - |
| Michaut et al. (40) | * | ns | | * |
| Seger and Thorstensson (58) | * | ns | - | - |
| Raue et al. (54) | ns | ns | - | - |

†* = significant increase; ns = not significant; - = not measured; () = not significant in all tests; 1RM = 1 repetition maximum; MIF = isometric maximum strength.

for the generation of hypertrophic effects (13,19,21,31,47,57). Komi and Buskirk (33) showed enhanced improvement in maximal force when using eccentric training compared with concentric strength training interventions. Other authors used eccentric training with supramaximal and submaximal loads to generate significant improvements in isometric, eccentric, and concentric maximal strength; however, these studies showed no superiority in eccentric or concentric muscle action over a normal strength training protocol (48). Nevertheless, Dudley et al. (15) showed that when eccentric strength training was part of the movement, it exerted a greater influence on the increase in strength because the exercise performance after training using both forms of muscle actions was superior to training using a purely concentric training. Kraemer and Häkkinen (34) emphasized that the extremely high stresses reached during the eccentric muscle action led to particularly high increases in strength. However, it must be stated that the scientific literature on the subject shows widely divergent results. Little information is available in the literature on the effects of changing speed strength and rate of force development (RFD) by training while using supramaximal loads. In contrast to most investigations, we used a multijoint exercise (leg press) in the eccentric training protocol to increase the chance of a transfer of an eccentric strength training protocol in speed-strength motor tasks, such as squat jumps (SJ) or countermovement jumps (CMJ).

The effects of training using eccentric muscle action with supramaximal loads on speed strength, the RFD and maximum strength or muscle activity in the context of isometric, concentric, and eccentric maximal strength tests have largely been ignored. Furthermore, most studies of eccentric strength training have used only single-joint strength training exercises.

The aim of this study was to investigate and consider the influence of a supramaximal eccentric strength training protocol with multijoint exercises on RFD and speed-strength parameters.

## Methods

### Experimental Approach to the Problem

This study provides information on the effects of an eccentric strength training protocol of the lower extremity using supramaximal loads on different speed-strength and maximal strength parameters. To accomplish these objectives, 28 male students were enrolled in this study. Fifteen subjects served as the training group, and the other 13 served as controls. The pretest and posttest were conducted during the week before training and 3 days after the last training session. The following parameters were tested: 1 repetition maximum (1RM), eccentric maximal strength (EX max), maximal isometric strength ("maximal voluntary contraction" [MVC]), explosive strength (rate of force development [RFD]), CMJ, and SJ height. The training period lasted 6 weeks. Training with eccentric muscle work was conducted 3 times per week. Exclusion criterion for participation was missing more than 2 training sessions. Thus, at least 16 training sessions must have been performed to be included in the evaluation.

### Subjects

For this study, 28 male students of the Institute of Sports Sciences at the University of Frankfurt am Main participated. Fifteen of the subjects served as the training group (24.1 ± 2.2 years, height = 180.1 ± 3.0 cm, mass = 76.3 ± 6.7 kg), and the other 13 served as controls (25.2 ± 2.7 years, height = 180.9 ± 6.1 cm, mass = 77.2 ± 6.8 kg). Approval for this study was obtained from the Institutional Review Board of Johann Wolfgang Goethe-University, Frankfurt, Germany. Randomization or parallelization of groups was not possible because not enough workout-willing volunteers were available. Both groups were composed of recreational athletes (sports students). The subjects in the control group were allowed only the usual leisure activities. All subjects had little or no experience in weight training. The investigators informed all subjects of the objectives of the investigation and of all aspects of the research. All participants provided written informed consent to participate.

### Procedures

*Testing.* Pretest and posttest were conducted during the week before training and after the last training session. The pretest was performed 3 days after a familiarization test. Data of the best attempt of these 2 tests (pretest and familiarization test) were used as the baseline to avoid overestimating performance parameters collected for each performance parameter. Three days after the last training session, the tests were performed again. The test protocol was divided into 2 testing days to eliminate possible common motivation problems or fatigue that can occur when the testing session lasts too long. Testing day 1 was completed 2 days before testing day 2. On testing days, anthropometric and performance measurements were collected at the same time by the same researchers, and all participants were asked to wear the same clothing and footwear. All participants were asked to eat and drink sufficiently until 1 hour before testing. On testing day after a standardized warm-up, the following tests in the displayed order were evaluated. Subjects were permitted 4- to 5-minute breaks between individual attempts and tests.

On the first testing day, the SJ (test-retest reliability $r = 0.87$ [$p < 0.01$]) and CMJ (test-retest reliability $r = 0.94$ [$p < 0.01$]) performances were also tested during test days to determine whether eccentric training with supramaximal loads affected speed-strength performance. The jump performances were measured using a contact mat (Refitronic, Schmitten, Germany) that operates as a switch. This system sends information to the computer as to whether the mat is loaded. From this information, the flight time and the jump height can be determined for all jumps. Also, eccentric maximum strength was evaluated using a 45° leg press (Rowe & Kopp, Oberursel, Germany). For safety purposes, in addition to the stoppers that are mounted as standard on the leg press, 2 straps were also used. The straps had a towing capacity of 600 kg and were able to stop the carriage if a subject could not control the load, particularly at smaller angles. In determining the maximum eccentric strength, the eccentric phase was required to last for 3–4 seconds (angular velocity of 25° per second at the knee joint) to be accepted as valid. If the subject could not prevent a faster lowering of the carriage, the test was considered invalid. The lowering was monitored using a knee brace attached to a goniometer. The subjects had a knee brace on their right knee to supervise the movement range in the knee joint while testing and training. At starting position (with both legs on the plate), a trigger was always set. The movement range was controlled visually by the investigators. The experiment concluded when a knee joint angle smaller than 90° had been reached. After reaching the 90° angle, the carriage of the leg press was brought to the starting position using 2 assistants. After each successful test, the load was further increased until the trials failed. Between individual attempts, the subjects were permitted 4- or 5-minute breaks. The test-retest reliability was $r = 0.96$ ($p < 0.01$).

On testing day 2, the isometric force was determined using a legwork machine (BAG, Wolf, Germany, test-retest reliability $r = 0.90$ [$p < 0.01$]) at the seated position, using a 60° hip angle and a 120° knee angle. The strength produced during each trial was recorded using strain gauges at a feed rate of 50 Hz and was plotted as force-time curves, indicating the force peak value. The tests were performed unilaterally. The dynamic (eccentric-concentric) maximum strength was estimated using the load from 1RM (unilateral). In a series of 1RM, the maximal load was determined. The criterion for a successful attempt was a trial in which the leg was completely outstretched. The range of motion was monitored also using a knee brace with a goniometer.

*Training*. The training period lasted 6 weeks. Training with eccentric muscle work was conducted 3 times each week. Training typically took place on Mondays, Wednesdays, and Fridays; thus, there was a 48-hour rest period between workouts. A total of 18 training sessions were completed. During the training session, after warm-up, 5 sets of 3 repetitions on the same 45° leg press used for the tests were performed. Participants took a 6-minute rest between sets. Three eccentric repetitions were performed per set. The load had to be lowered in approximately 3 seconds. The range of the movement was performed from a position of the leg being outstretched (180° knee angle) to a 90° knee angle. For each training set, a load was chosen that could be lowered by the subjects for maximal 3 repetitions (loads were higher than the eccentric-concentric maximal strength [supramaximal]). This procedure was used first, to standardize number of repetitions and second, to standardize physical exertion at the given number of repetitions. The same procedure was used to increase the load between workouts. With increasing performance (due to training effect), the loads were increased. If the subjects were able to do, each training session the loads were increased. After reaching the 90° angle, the carriage of the leg press was brought to the starting position using 2 helpers. Assistants lifted the sled to the starting position without the help of the participant. The second foot was placed in the turning point of the motion only to be secured to the carriage or for the acquisition of the slide with legs straight (starting position). The next repetition was performed from this position. At the beginning of each repetition, the carriage rested on both legs. The subject then removed 1 leg from the base of the carriage and began lowering the load.

To document the progress of training and to obtain additional information on the adjustment during the course of the 6-week training period, the lifted loads during training were analyzed. The total lifted loads (TOTAL) per training sessions were calculated. The mean load per lift ("medium dumbbell weight" [MHG], a term used in weightlifting as a parameter to monitor or control performance) and the maximal training load (MAX) were calculated. TOTAL parameter was calculated based on the appropriated series load multiplied by 3 (number of repetitions per series). The load lifted over the 5 series was then calculated. The MHG lifted was divided by the number of repetitions (15 per session). The maximum training load denotes the highest weight used in a training session.

**Statistical Analyses**

The collected data were checked for normality using the Kolmogorov-Smirnov test. We analyzed the test-retest reliability ($n$ = 28) for the normally distributed data using several bivariate correlations by Pearson and for the non-normally distributed data using several bivariate correlations by Spearman. We analyzed whether significant ($p \leq 0.05$) differences in performance parameters existed at the beginning of the study using $t$-tests for independent samples. For all group comparisons and comparisons of pretest and posttest results, 2-factorial analyses of variance were performed using a repeated measures model. The Mauchly sphericity test was performed before analysis of variances (ANOVAs). If sphericity was calculated as significant, the Greenhouse-Geisser correction was used. When significant $F$ values were returned, Scheffé's test was used for further post hoc analyses. To control for body weight changes during the study period, paired $t$-tests were calculated.

## Results

Mean and *SD*s of test parameters (pretest and posttest) are displayed in Table 2. During the intervention period, there was a significant increase of 28.2% in maximal eccentric strength in the experimental group. A 2-factorial ANOVA with repeated measures showed a significant effect of both the repeated measures factor ($F$ = 13.857, $p$ = 0.001) and training ($F$ = 12.212, $p$ = 0.001).

The mean of the 1RM in the experimental group increased by 31.1%. There was an increase of 7.8% in the control group. A 2-factorial ANOVA with repeated measures showed a significant effect of both the repeated measures factor ($F$ = 17.434, $p$ = 0.000) and of training ($F$ = 11.353, $p$ = 0.002). Post hoc Scheffé's tests revealed that the change in the experimental group was significant, whereas the increase in the control group was not significant. When compared with the control group, the experimental group increased their 1RM significantly during the study period. The increase in maximal eccentric strength resulted in an interaction between factors. The 2-factorial ANOVA with repeated measures showed no significant overall effect of time ($F$ = 1.254, $p$ = 0.273), but training resulted in a highly significant effect ($F$ = 14.067, $p$ = 0.001).

The maximal isometric strength did not change significantly in either group (5.4% in the experimental group and −9.9% in the control group). This interaction caused the significant interaction effect of the results. The 2-factorial ANOVA with repeated measures showed no significant effect of either time ($F$ = 2.323, $p$ = 0.141) or training ($F$ = 3.310, $p$ = 0.081). The RFD changed by +2.0% in the experimental group and by 11.9% in the control group.

During the evaluation period, there was a significant decrease in squat jump performance in the control group, whereas only a slight decrease was observed in the mean jump performance in the experimental group, which did not reach significance (criterion set to 5%). The 2-factorial ANOVA with repeated measures showed a significant effect of time ($F$ = 5.159, $p$ = 0.032) but not of training ($F$ = 0.076, $p$ = 0.785). On average, the jump performance decreased by 2.3% in the control group and by 1.9% in the training group. The 2-factorial ANOVA with repeated measures revealed a significant effect of time on CMJ parameters ($F$ = 16.765, $p$ = 0.000) and a significant effect of training ($F$ = 14.649, $p$ = 0.001), caused by the hybrid interaction. Whereas performance in CMJ in the control group decreased by −5.5%, this remained consistent in the experimental group (an increase of 0.03%) (Table 2).

For TOTAL and MAX the highest load lifted and the MHG could be recognized an increased from training session to training session. This trend continued for almost the entire 6-week training period. After 4 weeks (approximately 12 sessions), the curve began to flatten, indicating a reduction in the growth rate relative to the weights used in the training sessions (Figure 1).

**Table 2.** Development of power parameters in the experimental and control groups.†

| | Experimental group ($n$ = 15) | | Controls ($n$ = 13) | | |
|---|---|---|---|---|---|
| | T1 | T2 | T1 | T2 | G-diff |
| EX max (kg) | 193.8 ± 66.3 | 325.7 ± 41.0* | 178.1 ± 54.7 | 167.8 ± 33.8 | * |
| 1RM (kg) | 97.8 ± 31.2 | 122.3 ± 29.3* | 91.9 ± 36.7 | 94.6 ± 27.0 | * |
| MIF (N) | 2,506.6 ± 413.5 | 2,621.3 ± 338.3 | 2,244.0 ± 320.5 | 2,031.7 ± 432.6 | * |
| RFD (N·ms$^{-1}$) | 11.5 ± 2.3 | 11.6 ± 2.6 | 11.3 ± 2.2 | 9.9 ± 2.6 | ns |
| SJ (cm) | 40.6 ± 8.0 | 39.5 ± 6.1 | 38.5 ± 4.4 | 37.7 ± 4.6 | ns |
| CMJ (cm) | 43.1 ± 7.6 | 43.1 ± 7.3 | 42.7 ± 5.8 | 40.4 ± 6.1 | * |

†T1 = pretest; T2 = posttest; G-Diff = group differences; EX max = eccentric maximum strength; 1RM = eccentric-concentric maximum strength; MIF = isometric maximum strength; RFD = rate of force development; SJ = squat jump; CMJ = countermovement jump; ns = not significant; *$p < 0.05$.

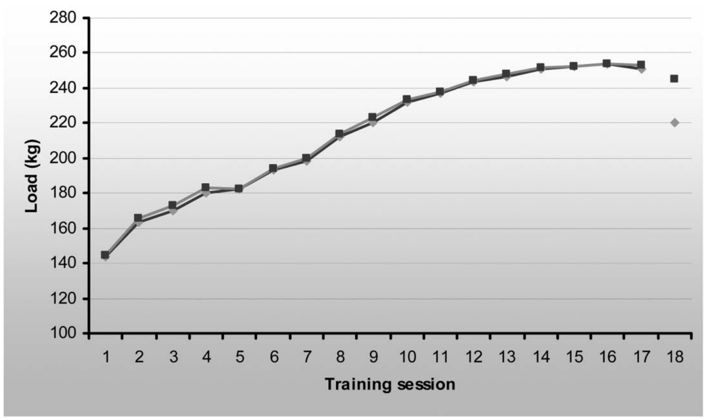


**Figure 1.** Change in maximum training load lifted (square) and the mean weight used (diamond) in training sessions over the 6 weeks (session 18 is not connected because of missing values).

The last training session was removed from the trajectory because several subjects did not attend this training session; thus, these data are not meaningful. On average, the MHG changed during the experiment from 143.5 kg to a maximum of 253.9 kg, corresponding to an increase of approximately 77%. The maximum load within each training session increased from 144.5 to 253.9 kg, representing an increase of almost 76%. Thus, these 2 parameters are very closely correlated. This can be explained by the fact that during the experiment, consistency in the lifted loads was observed. Thus, in many cases, the same load was used in all 5 series. Therefore, as expected from this trend, the total load increase per workout is very similar. This value also increased steadily from the first to the 16th workout and then fell slightly at the 17th. The mean load volume (expressed here as the total lifted load per training session) increased from 717.6 to 1,269.3 kg during the 6-week training period (Figure 2).

The maximal eccentric strength at the beginning of the study was approximately 203.7% of the 1RM. It was approximately twice as high as the 1RM and remained nearly unchanged until the end of the study (EX max = 195.8% 1RM). When comparing the MHG of both maximal strength values, the average training load at the beginning of the study was 151.0% of the 1RM and 74.8% of the eccentric maximum strength. At the end of the investigation, the MHG was 214.2% of the 1RM and 109.7% of the eccentric maximum strength. This apparent contradiction that resulted from the training load being slightly higher than the eccentric maximum strength measured at the end of the study may be explained by the fact that training was always performed close to the maximum performance level. Under these circumstances, a controlled lowering of the loads to a 90° angle was not always possible. To ensure that the load was released in a controlled manner, an additional criterion for a valid test was that a maximum eccentric angular velocity of 25° per second be maintained. This angular velocity was lower than the actual speed used when lowering the load, as observed during some repetitions in training. In addition, 2 subjects did not show benefits of training, for reasons not apparent in the initial tests.

The results presented above provide an indication that the maximal load and the MHG in training sessions were very closely correlated. To verify this relationship, an ANOVA was performed with repeated measures and using post hoc Scheffé's tests. We analyzed the change in training load over the series. As observed in Figure 3, a slight, nonsignificant increase in training load (relative to the training load used in the first series) was detected during training sessions. The largest difference was observed between the first and the fifth series. This increase was 1.36%, which may be regarded as marginal. This means,

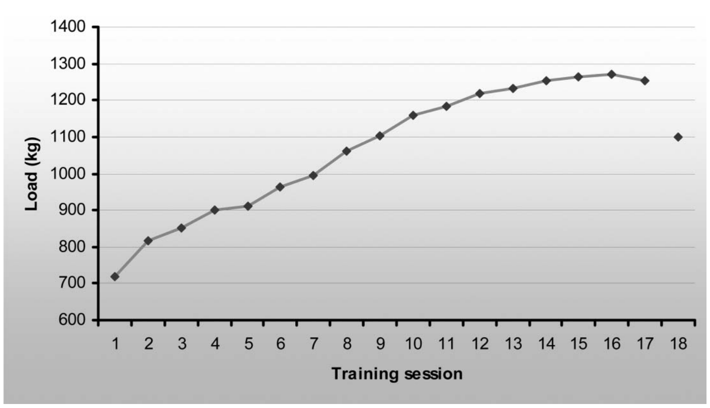


**Figure 2.** Change in total training load (sets × reps × load) per workout (session 18 is not connected because of missing values).

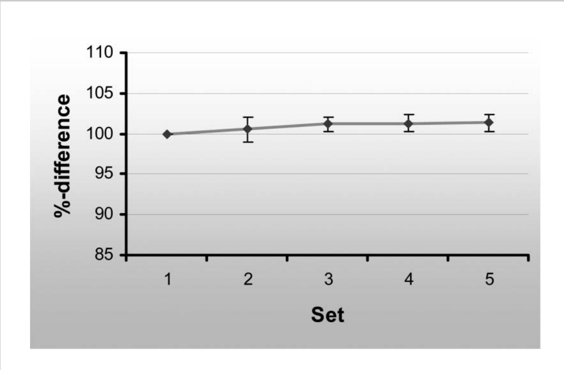


**Figure 3.** Medium relative increase in training load over sets within a training session.

in general, the weight of the first series could be maintained throughout all the series. The slight and perhaps unexpected increase is due to the increase in training loads during the first training sessions. In particular, during the first 2 weeks, the loads in the majority of cases increased in these training sessions. The speed of progress may be determined from the fact that loads of the eccentric maximal pretest were used as training loads by all subjects within a few training sessions.

## Discussion

This study aimed to provide information on the effects of eccentric strength training for the lower extremity using supramaximal loads and different speed-strength and maximal strength parameters. In contrast to the majority of studies that examined eccentric strength training, in this study, we report about multijoint strength training exercises to train the lower extremities and thereby increase the likelihood of a positive effect of a strength training intervention, primarily on jump performance. This study used a population of participants with low-strength training experience, which is favorable and should increase the likelihood of a transfer of the increased eccentric strength level to the performance of other test parameters. As expected, the eccentric strength training led to a significant increase in eccentric maximal strength (28.2%, $p < 0.001$) in the training group. Thirteen of the 15 subjects in this group improved their performance in this test criterion. As shown by the training data, both the training load and the maximum load increased steadily over the 6-week period. A similar rapid increase in training loads was also demonstrated by Johnson et al. (26) in his strength training study. During the first training session, the load was approximately 151% of the 1RM. By the end of the study period, the load was approximately 214%. When examining only the change in eccentric maximal strength and predicting the causes underlying this increase in strength, it must be assumed, based on current literature, that the increase in this strength parameter is primarily because of neural adaptations (1,3,8,11,41,53,61). This explanation does not mean that the training intervention is generally insufficient in producing hypertrophic effects, but rather that a longer training period would have been required to produce detectable changes in hypertrophic effects. A training period of 6 weeks may be sufficient to enlarge muscle cross-sectional volume, as has been shown in several studies (2,18,38,50,65,68). However, a rather low initial performance level is necessary to detect an increase in muscle thickness over such a short period of time. In general, however, neural adaptations to strength gains during the first few weeks of strength training are likely because this adjustment mechanism is detectable after just a few workouts. This assumption is supported by the fact that when learning a new training exercise, progress in exercise performance may be achieved between workouts, which must, at the very least, be attributed to changes in intermuscular coordination and improved intramuscular coordination. This theory is supported by the study of Hortobagyi et al. (23), who reported that approximately 20 subjects, who trained for 7 consecutive days, showed significant increases in both the eccentric and concentric maximal strength. The proportion of the changes due to intermuscular or intramuscular neural adaptations remains unknown. A purely eccentric strength training protocol has also been used in several studies and shown to produce hypertrophic adaptations (17,21,45). The increase in 1RM of 30.1% ($p < 0.001$) was in the same range as the increase in eccentric maximal strength. The load lowered in the leg press both before and at the end of the study was approximately twice that performed for the 1RM. The data from this investigation show clearly that training with eccentric movement causes increases in eccentric test parameters (e.g., 1RM, here concentric strength is performance limiting). This fact has been proofed by investigations analyzing strength training inexperienced subjects (see references listed in Table 1).

In the majority of studies, the increase in maximal eccentric strength is greater than that of the 1RM, which represents the eccentric-concentric maximum strength. These findings are most evident in the investigations of Hortobagyi et al. (22–24). In one study, all subjects except 1 showed an increase in 1RM. However, a different picture emerged for maximal isometric strength: the training group showed no significant increase in this test parameter. In 4 of the 15 subjects, this parameter remained almost identical between tests and decreased in 3 subjects. The expected transfer of enhanced strength for this test was not evident. Sale et al. reached the same conclusion (55). These authors used a protocol that comprised a 19-week period in which 8 subjects trained 3 times per week using dynamic resistance training on a leg press. At the end of the training period, an improvement in 1RM by 29.1% ($p < 0.01$), and an increase in muscle cross-sectional area of 10.8% (left leg, $p \leq 0.05$) and 11.1% (right leg, $p \leq 0.05$) of the knee extensors were observed. However, isometric strength, in single-legged testing of the knee extensors, showed no significant change in maximal isometric strength. These data show that a change in muscular work and tests can lead to significant increases in the cross-sectional area of the knee extensors but does not necessarily lead to an increase in measured strength values if the tests are not performed identically to the training exercises. The results of the RFD measurements under isometric conditions were quite similar. Only 5 of the 15 subjects improved this parameter during the investigation period. Based on the relationship between maximal strength and RFD (43,49), an increase in this parameter is expected, as shown in several strength training studies (7). Thus, both test parameters that were measured during isometric conditions were not improved. This finding indicates that a transfer between 2 dynamic test conditions is more efficient than between dynamic and isometric conditions. The correlation coefficient between the 2 maximal force parameters recorded under dynamic conditions was $r = 0.78$ ($p < 0.01$); however, when the maximal strength was recorded under isometric conditions, the correlation was significantly lower. The correlation between eccentric and isometric maximal strength was $r = 0.56$ ($p < 0.01$) and between the 1RM and the isometric maximum was $r = 0.58$ ($p < 0.01$).

Several studies have shown that the 3 highest forms of contraction strength values correlate from $r = 0.48$ to $r = 0.90$ ($p \leq 0.05$ to $p < 0.01$) (14,25,43,63). However, the chosen test angle (isometric) influences the correlation (14,25,67). This seems to be due to the different capacity to activate the muscles used in the 3 muscular ways of working. Thus, several researchers have shown varying degrees of activation of the working muscles during maximal eccentric work compared with maximal concentric work. In a number of investigations, the activating ability during eccentric work was less than the ability to activate during concentric work (5,30,32,33,37,59,66). Isometric RFD values were not increased significantly by strength training using eccentric work. Because of the significant maximal increase in maximal strength in dynamic tests, an increase in RFD was expected because a number of studies have shown that strength training improves maximal strength and increases RFD (7,8). Therefore, it must be assumed that he different test conditions in this investigation resulted in the lack of change in this parameter. The final 2 parameters that were determined were the SJ and CMJ. Only concentric work is tested during the SJ, and a slow stretch-shortening cycle is observed in the CMJ. Both jumps were used to determine the influence of an eccentric strength training protocol with supramaximal loads on speed-strength motor tasks. In both cases, the strength training with eccentric work did not improve jump performance despite increasing maximal eccentric and concentric-eccentric maximal strength. Because the level of performance of the trained subjects was determined to be low to moderate, an increase in jump performance for both jumps could be expected despite the nonspecific training. Moreover, because there was an improvement in the 1RM, and thus a higher efficiency in concentric work, the only explanation for the lack of improved performance in the SJ and CMJ is that while in the concentric phase of movement, a higher force value was realized but was not accompanied by a sufficiently rapid development of strength because of the limited time that is available for body acceleration. The RFD is of crucial importance for improving these 2 test parameters. The increase in maximal strength values (1RM and EX max) can be explained by adaptations of the nervous system. It seems that after the training period, the modified neuronal activation exploits the muscle potential in a more effective way. However, this neuronal improvement does not automatically lead to more rapid activation of the performance-related muscles during execution of the jump forms. Again, we note that no fast RFD was produced during the execution of training exercises, which is regarded as an important factor when the goal of the training is to increase the speed strength (6,9,70).

It should be noted that training of the lower extremities using supramaximal loads only resulted in a positive impact within the study period of 6 weeks on the eccentric maximal strength and the 1RM. However, the parameters that included the execution of a highly dynamic movement or those collected under isometric testing conditions remained unchanged. The significant increase in maximal eccentric strength resulted in a transfer to the 1RM and in no transfer to the maximal isometric force. Thus, it must be noted that eccentric strength training, at least in the short term, triggers very specific adaptations even in untrained subjects.

## Practical Applications

Eccentric strength training was performed unilaterally because of the high-weight loads that were necessary to apply an above-threshold stimulus. Bilateral training was not manageable, neither with personal assistance nor with the training apparatus. This fact could also have influenced the transfer effect to the bilateral speed-strength action of the vertical jumps. However, the low-to-medium training status should have been advantageous for neural transfer effects to the speed-strength behavior, even for unilateral strength training, because it produced equal and significant improvements in the eccentric-concentric test (1RM). Implementation of this training regime as a hypertrophy block in the general stage of speed-strength events could be a viable option. However, based on the present findings, in the special periodization stage before competition, eccentric strength training with supramaximal loads cannot be recommended because of missing transfer effects. Strength or power sessions with traditional eccentric-concentric strength training should be used because of the established positive training effects in increasing vertical jump performance.

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