Effects of standard and eccentric overload strength training in young women

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ABSTRACT

HORTOBÁGYI, T., P., DEVITA, J. MONEY, and J. BARRIER. Effects of standard and eccentric overload strength training in young women. *Med. Sci. Sports Exerc.*, Vol. 33, No. 7, 2001, pp. 1206–1212. **Purpose:** According to the force-velocity relationship of human skeletal muscle, the maximal load one can lift is limited by the concentric movement phase, and the eccentric phase is always underloaded. In the present study, we hypothesized that acute exercise training using an eccentric overload compared with standard loading would lead to greater neuromuscular and strength adaptations. **Methods:** Sedentary women (age 20.9 yr) were tested for concentric and eccentric three-repetition maximum (3RM), maximal isokinetic eccentric and concentric and isometric force and associated EMG activity of selected thigh muscles before and after 7 consecutive days of exercise training of the left quadriceps. The exercise program was designed so that the total weight lifted was similar between the eccentric overload (EO, $N = 10$) and standard group (ST, $N = 10$), but EO exercised with about 50% greater eccentric load whereas the controls did not exercise ($N = 10$). **Results:** There was a 22% increase in the total weight lifted over 7 d. On the average, EOs compared with STs strength gains were ~twofold greater. Changes in EMG paralleled the changes in muscle strength without changes in biceps femoris coactivity during knee extension. **Conclusion:** Because the strength gains were achieved by exercising at low intensities and over a short time period, exercise prescription of eccentric overloading appears especially suitable for elders, individuals deconditioned due to an injury, and the chronically diseased. **Key Words:** EXERCISE, MUSCLE, ECCENTRIC CONTRACTION, ELECTROMYOGRAPHY, COACTIVATION

Conventional resistive exercise involves sequences of eccentric and concentric contractions, with a brief isometric contraction coupling the two phases of movement. A person's ability to complete an eccentric-isometric-concentric cycle under maximal load is limited by the force production in the concentric phase. This limitation is described by the force-velocity relationship (20). For example, when the one repetition maximum (1RM) is separately assessed for the concentric and the eccentric phases of the supine leg press, during the eccentric phase one can lower about 40–50% more weight than one can lift during the concentric phase (8). Clearly, when the eccentric and concentric phases of the leg press are performed during typical weight training bouts, the eccentric phase is substantially underloaded. Such observations raised the question, would acute strength gains be superior using a paradigm in which the eccentric phase of the movement is overloaded compared with exercise using a conventional loading pattern?

Additional experimental data also suggest that resistive exercise with an eccentric overload may lead to heightened neuromuscular adaptations. Skeletal muscle responds to a mechanical stimulus in proportion to the magnitude of the stimulus. Subjected to an eccentric contraction, skeletal muscle produces significantly greater force compared with the force at the same velocity of shortening (20). A series of human studies using a variety of experimental manipulations have demonstrated the potency of eccentric contractions to improve contractile characteristics and muscle size in humans (8,14,15,18). Indeed, strength gains were greater with the standard eccentric-concentric sequence of leg press compared with exercise training that doubled the concentric load (8).

Based on such observations, the hypothesis of an augmented neuromuscular adaptation to exercise training with an eccentric overload seems tenable. We are aware of only two studies that examined the strength responses to exercise training with an eccentric overload and the results are equivocal (11,25). Exercise with an eccentric overload compared with conventional exercise resulted in superior strength gains in aged subjects (25), but in young subjects no such superiority was observed (11). We sought to resolve these discrepancies and to evaluate more systematically the possible neural mechanisms of adaptations to resistive exercise. Because the initial adaptations to resistive exercise especially with an emphasis on eccentric contraction are neural (28), we examined the acute changes in muscle strength, electromyographic (EMG) activity, and antagonistic muscle coactivity. Therefore, the purpose of the study was to compare the neuromuscular adaptations with acute exercise training incorporating an eccentric overload and exercise training with a conventional loading composition.

METHODS

Subjects and Design

Subjects were 30 normally sedentary Caucasian women recruited from the university campus by word of mouth and

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newspaper advertisements. Subjects' mean (±SD) age, height, and mass were 20.9 (±1.2) yr, 1.59 (±0.04) m, and 61.3 (±7.2) kg, respectively. All subjects were right-leg dominant based on a ball-kicking test. A subject was included in the study if, at the time of the experiment, she was not engaged in regular physical activity, had not exercised more than once per week for 1 yr before the study, had no orthopedic or neurological abnormalities of the lower extremities, and signed a consent form.

Subjects underwent an initial test, 7 consecutive days of exercise training, and a final test. The tests involved an assessment of maximal leg strength using a three repetition-maximum protocol (3RM), maximal isokinetic and isometric quadriceps strength, and associated surface electromyography (EMG). Subjects were ranked based on 3RM strength. From trios of ranked subjects, one was randomly assigned to the eccentric overload (EO, $N = 10$), one to the standard (ST, $N = 10$), and one to the nonexercising control (CON, $N = 10$) group.

Testing Protocols

Maximal voluntary isometric and isokinetic strength. Maximal voluntary isometric and isokinetic eccentric and concentric quadriceps strength of the left leg was measured on a Kin-Com 500H dynamometer (Chattecx, Inc., Chattanooga, TN). As a warm-up, subjects rode a bicycle ergometer at 60 RPM for 5 min at 1- to 2-kg resistance and performed 3 min of lower-extremity stretching. After the warm-up, subjects were seated on the dynamometer's seat with a hip angle of 1.57 rad. The center of the left knee joint was aligned with the axis of the dynamometer's power shaft. Shoulder straps, a lap belt, a knee strap, and an ankle cuff were used to minimize extraneous movements. The leg was fastened to the dynamometer's lever arm just above the lateral malleolus with a padded cuff that contained the strain gauge. The cuff slides on the lever arm. The distance between the strain gauge and the lever arm's axis of rotation was entered in the computer as the lever arm length. The knee angle anatomical zero was set at 3.14 rad. The weight of the leg was determined at 3.14 rad of knee joint position. By using these procedures, the dynamometer's software corrected the force exerted by the subject for the gravitational effects of leg mass. Familiarization with the dynamometer included two trials of 50%, 75%, and 90% of maximal intensity isometric, eccentric, and concentric contractions separated by 1 min of rest. Subjects were not allowed to grasp the seat and kept their hands in their laps.

Maximal isometric force was measured at 1.14 rad of knee flexion. Subjects performed three maximal effort, 5-s trials with 1 min of rest between trials. Subjects also performed three maximal effort eccentric and concentric isokinetic quadriceps contractions at 1.57 $\text{rad}\cdot\text{s}^{-1}$. We used this specific testing speed because it resembled the estimated knee joint angular velocity of the knee extension used during exercise training. There was 1 min of rest between conditions. The order of isometric and dynamic testing was systematically alternated between subjects. Peak dynamic forces were digitized at 1.14 rad of knee flexion. The highest force value of the three trials was used in the statistical analyses.

Surface electromyography (EMG). The skin surface over the belly of the left vastus lateralis, vastus medialis, and the biceps femoris were palpated, shaved, and washed with alcohol. The skin over the right fibula head was similarly prepared. Two single-use diagnostic ECG electrodes (ConMed Inc., Utica, NY), touching rim-to-rim, were placed on each muscle belly with a 3.5-cm center-to-center interelectrode distance to detect surface EMG activity. One ground electrode was placed on the skin over the right fibula head. The EMG data were collected with the TeleMyo telemetric hardware system (Noraxon U.S., Inc., Scottsdale, AZ). We previously described the technical details of the transmitter, receiver, and signal conditioning process (17). All signals were digitized at 1 kHz using the Myosoft software (Noraxon Inc.).

EMG data reduction consisted of the full-wave rectification and root-mean-square (RMS) conversion of the direct EMG data by a 20-ms smoothing window. The trials of maximum force were identified, and in these trials the corresponding peak RMS EMG activity was digitized for the three muscles. Biceps femoris coactivity during the quadriceps testing was computed as the quotient of peak RMS amplitude of the biceps femoris divided by the peak RMS amplitude of the vastus lateralis. Figure 1 displays a typical recording in one subject before and after the 7-d exercise program.

Three-repetition maximum (3RM). Unilateral (left leg) concentric and eccentric 3RM tests of the quadriceps muscle were determined on a separate day relative to the tests administered on the dynamometer. The 3RM tests were performed on a Cybex knee extension unit (model no. 4100, Cybex Inc., Owatonna, MN).

Concentric and eccentric 3RM were defined as the amount of weight a subject was able to lift or lower three times, respectively. Because we plan to compare the adaptations between young and old subjects, we used a 3RM and not a 1RM to reduce the number of unilateral maximal efforts during testing, and the 3RM will also allow us to set lower training weights (16). Concentric 3RM was determined first. At a 3-s count pace, subjects lifted and lowered the weight with one smooth movement during each phase. The weight for the first attempt was about 50% of the estimated 3RM weight. Weight was then progressively added in 10- to 45-N increments until the 3RM was reached with ~3 min of rest between efforts.

Eccentric 3RM was assessed by a technician manually lifting the weight that was one step below the previously determined concentric 3RM. The subject extended her knee, the technician let the weight go, and the subject lowered the weight to a 3-s count from 3 rad to 1.57 rad of knee joint position. The same technician administered the 3RM tests with the aid of a metronome. This cycle was repeated until the subject could no longer lower the weight three times in

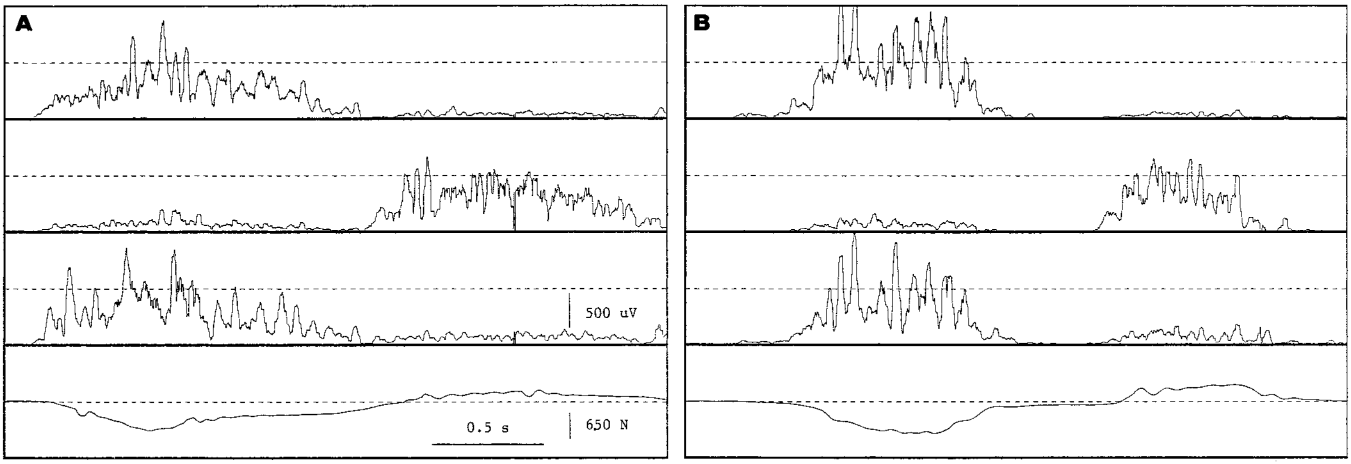

FIGURE 1—Root-mean-square processed surface EMG activity of the vastus lateralis (top tracing), biceps femoris (second tracing from top), vastus medialis (third tracing), and eccentric quadriceps force (fourth tracing) before (A) and after (B) 7 d of eccentric overload exercise training of the quadriceps muscle in a 20-yr-old previously sedentary woman. In each panel, one quadriceps (downward deviation in force) and one hamstring effort is illustrated. *Calibration bars* refer to both panels A and B.

a controlled fashion. No subject did more than six attempts to reach the concentric and eccentric 3RM, respectively.

Training Protocol

Subjects warmed up for each session by riding a bicycle ergometer for 5 min at 1–2 kg and by performing general lower body flexibility exercise. Exercise training consisted of 5–6 sets of 10–12 left quadriceps contractions for 7 consecutive days, corresponding to a training intensity of about 60% of 1RM. There was 3 min of rest between sets to avoid overtraining.

Subjects exercised on the same Cybex machine that was used for the 3RM testing. Unilateral knee extension was the choice of exercise to isolate the quadriceps muscle group. Subjects assigned to the “standard” (ST) group exercised using a conventional sequence of concentric followed by an eccentric quadriceps contraction. Subjects in the eccentric overload (EO) group used the same sequence, but an overload of 40–50% was added during the eccentric contraction. In a previous study, the eccentric phase was about 50% underloaded relative to the knee extension phase using the leg press (8).

The training programs were designed so that the total weight lifted by ST and EO was similar. The eccentric overload was accomplished by a technician manually attaching extra weight plates to the main weight stack at the instant the subject reached the end point of the lifting phase. The extra load was removed after the lowering phase was completed. To equate total load between ST and EO, EO subjects performed fewer repetitions. For example, if a ST subject lifted 23 kg of mass, she would perform 5 sets of 12 repetitions, 23 kg for both the concentric and the eccentric phases, a total of 2760 kg. To equate the load, the paired EO subject would perform 5 sets of 10 repetitions, 23 kg concentrically and 32 kg eccentrically, a 40% overload, a total of 2750 kg. Matched pairs of subjects were monitored so that as one subject improved, the paired subject’s training weight was adjusted to equate the training weight between the two subjects. The weight, the number of repetitions, and number of sets performed by each subject were recorded for the seven training sessions.

Statistical Analysis

All data analyses were performed with the BMDP PC-90 software. By using the control group’s pre and post data, reliability was estimated with a Pearson product moment correlation coefficient, and the differences in the means of the repeated measurements were analyzed with a paired, two-tailed *t*-test. Because eccentric, isometric, and concentric forces are substantially different and ANCOVA would misleadingly adjust the posttraining scores for these initial differences, these analyses were done on the gain scores (i.e., absolute change). Accordingly, a group (EO, ST, CON) by contraction mode (eccentric, concentric) analysis of variance with repeated measures on contraction mode was used to analyze the changes in concentric and eccentric 3RMs. A group (EO, ST, CON) by contraction mode (eccentric, concentric, isometric) ANOVA with repeated measures on contraction mode was used to analyze the gains in isokinetic and isometric forces and changes in EMG activity. The total mean weight lifted during exercise training was analyzed with a group by contraction mode by time ANOVA with repeated measures on the last two factors. Tukey’s *post hoc* contrast was used to identify the means that were significantly different ($P < 0.05$).

RESULTS

Reliability

Repeated measures of isokinetic eccentric and concentric and isometric force and the associated measures of vastus lateralis, vastus medialis, and biceps femoris EMG activity and the measure of 3RM were stable and reliable. The

TABLE 1. Total mean weight lifted by subjects during a 7-d eccentric overload ($N = 10$) and standard load ($N = 10$) weight lifting exercise program.

	Eccentric Overload		Standard Load		Time Effect	
Day	Mean	±SD	Mean	±SD	Mean	±SD
1	13,687	3,244	13,714	3,967	13,701	3,601
2	13,992	2,941	13,866	3,911	13,929	3,426
3	14,361	3,111	14,258	4,316	14,445	3,714
4	14,778	3,537	14,715	4,334	14,747*	3,936
5	15,566	3,921	15,447	4,288	15,507*	4,105
6	16,004	3,444	16,197	3,762	16,101*	3,603
7	16,698	3,145	16,603	3,006	16,651*	3,076
Group effect	15,012	3,335	14,971	3,941		

Values are in Newtons.

* Significantly different from previous values ($P < 0.05$).

For the time main effect, the weight versus day relationship is described by the $y = 509.1x + 12,975$ linear regression equation ($r = 0.96$, $F = 255.1$, $P = 0.0001$).

reliability coefficients for these measures ranged from r = 0.87 (VL EMG activity for isometric force) to r = 0.96 (isometric force), with the largest percent mean difference of 4.2% (VM EMG activity for concentric force).

Exercise Training Data

All subjects completed the study without injury. Table 1 shows the total mean weight lifted and lowered by ST and EO subjects. The group by contraction mode interaction ($F = 1.2$, $P = 0.3321$) and the group main effect ($F = 0.9$, $P = 0.4985$) was not significant. The time main effect was significant, and the 22% increase in the total weight lifted from day 1 to day 7 demonstrates that a training adaptation occurred ($F = 6.7$, $P = 0.0001$). The actual training loads corresponded to about 80% of 3RM or about 60% of 1RM. Neither the young nor the older subjects reported muscle soreness associated with training.

The group by movement phase (concentric, eccentric) interaction for average total weight was significant ($F = 12.7$, $P = 0.0001$). Over the 7 d, the average total weight lowered in the eccentric phase (63,052 ± 3,432 N) was 50 (±13)% more than the weight lifted in the concentric phase (42,034 ± 2,946 N) in the EO group. The average total weight was, by design, similar for the lowering and lifting phases of the knee extension exercise in the ST group, 52,400 (±1,999) and 52,400 (±1,999) N, respectively. The EO group thus lifted 20% less weight and lowered 20% more weight than the ST group (both $P < 0.0001$).

Changes in 3RM

Figure 2 shows the group (EO, ST, control) by contraction mode (eccentric, concentric) significant interaction of the 3RM gain scores ($F = 6.9$, $P = 0.0031$). Eccentric 3RM increased by 27% or 125 N in EO and by 11% or 49 N in ST. The 125-N gain in EO was significantly more than the 49-N gain in ST ($P < 0.05$). The change in the control group was 11 N. Concentric 3RM increased to the same extent in the two exercise groups, by 27% or 65 N in EO and by 26% or 58 N in ST (both $P < 0.05$). The change in the control group was 9 N. In EO, the 125 N gain in eccentric 3 RM was significantly more than the 65 N gain in concentric 3RM ($P < 0.05$). In ST, the 58 N gain in concentric and the 49 N gain in eccentric 3RM were statistically similar ($P > 0.05$).

Changes in Isokinetic and Isometric Forces

At the pretest, subjects' force production followed the expected pattern according to the force-velocity relationship, i.e., concentric force (404 ± 77 N) was the least, exceeded by isometric (448 ± 90 N) and eccentric forces (648 ± 111 N). Figure 3 shows the significant group by contraction mode interaction of the gain scores ($F = 5.4$, $P = 0.0241$). Tukey's *post hoc* contrast revealed that EO's gains of 149 N, 58 N, and 59 N in eccentric, isometric, and concentric, and isometric forces were significant. ST's gains of 64 N and 53 N in eccentric and concentric forces were also significant ($P < 0.05$). EO's 58-N gain in isometric force was significantly greater than ST's gain of 27 N in isometric force ($P < 0.05$). The changes in the control group were not significant.

Changes in EMG Activity

Changes in EMG activity of the vastus lateralis and medialis were proportional to the changes in isokinetic and isometric force. Figure 4 shows that the group by

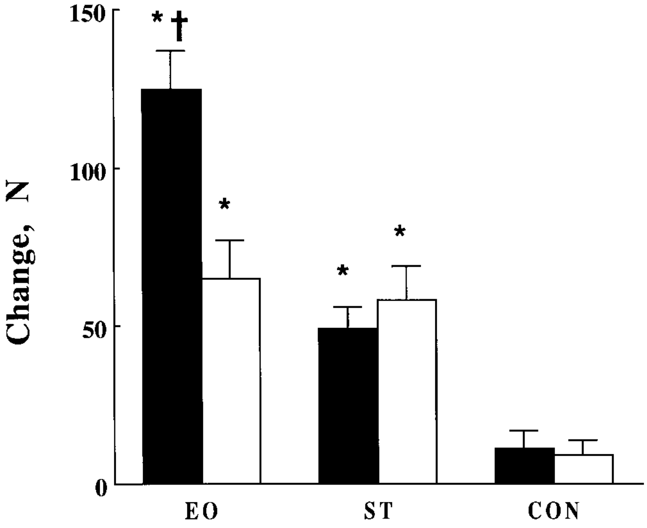

FIGURE 2—Absolute changes (in Newtons) in eccentric (*closed bars*) and concentric 3RM in the eccentric overload (EO), standard (ST), and control groups. The 125-N change in eccentric 3RM in EO was about 2.9-fold more than the change in concentric 3RM in ST; * significant pre- to post-training change and † significantly greater changes than any other changes ($P < 0.05$); *vertical lines* denote +1SD.

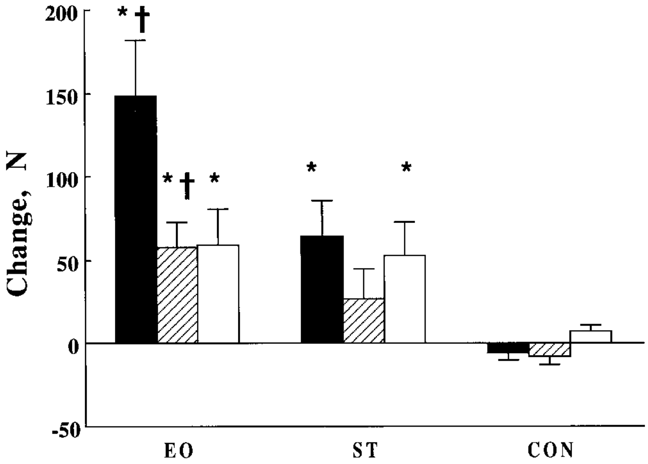

FIGURE 3—Absolute changes in isokinetic eccentric (*filled bars*), isometric (*hatched bars*), and isokinetic concentric forces in the eccentric overload (EO), standard (ST), and control groups. The largest gain occurred in eccentric force in EO (149 N) that was 2.8-fold more than the change in concentric force in ST; * significant pre- to post-training change and † significantly greater changes than the changes in the same measures in ST ($P < 0.05$); *vertical lines* denote +1SD.

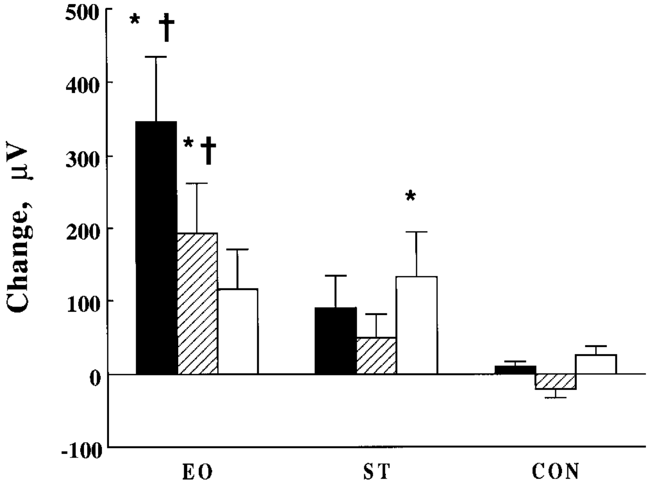

FIGURE 4—Absolute changes in vastus lateralis root-mean-squared EMG activity during isokinetic eccentric (*filled bars*), isometric (*hatched bars*), and isokinetic concentric forces in the eccentric overload (EO), standard (ST), and control groups; * significant pre- to post-training change and † significantly greater changes than the changes in the same measures in ST ($P < 0.05$); *vertical lines* denote +1SD.

contraction mode interaction of the gain scores was significant for VL EMG activity ($F = 4.9$, $P = 0.0349$). In EO, VL EMG activity during the eccentric test increased by 347 μV, significantly more than the 194-μV increase during the isometric or the 117-μV gain during the concentric test ($P < 0.05$). In ST, the 133-μV gain was significantly more than the 91-μV gain during eccentric and the 50-μV gain during isometric test ($P < 0.05$). EO's 194 μV increase was significantly more than ST's 50 μV increase during the isometric test ($P < 0.05$). The largest change in the control group was 25 μV. The direction and magnitude of the changes were similar in the vastus medialis compared with the vastus lateralis (data not shown).

The pretraining to posttraining change in the force to EMG ratio was computed for each subject by using eccentric, isometric, and concentric force and the associated EMG activity. The group by contraction mode interaction and the group main effect were not significant. The contraction main effect was significant ($F = 8.9$, $P = 0.0084$). The eccentric force to EMG ratio was significantly greater (0.59 ± 0.22 N/μV) than the isometric (0.31 ± 0.22 N/μV) or the concentric ratio (0.29 ± 018 N/μV).

The biceps femoris EMG coactivity was determined relative to the EMG activity of the vastus lateralis during eccentric, isometric, and concentric contractions. The coactivity ratio was not different between the groups or contraction modes. The coactivity ratio was 0.22 (±0.13), 0.25 (±0.15), and 0.25 (±0.16) for eccentric, isometric, and concentric contractions, respectively. The time main effect for the coactivity ratio revealed a 12% (±9) decline but due to the high variation in the ratios, this reduction was statistically not significant ($F = 1.2$, $P = 0.2245$). The changes in biceps femoris coactivity during eccentric, isometric, and concentric knee extension were 86 (±60), 5 (±18), and 37 (±44) μV, respectively.

DISCUSSION

Exercise with an eccentric overload, compared with conventional resistive exercise, resulted in greater strength gains in eccentric and isometric strength and similar strength gains on concentric strength. The strength gains were associated with proportional changes in muscle activation measured by surface EMG. The strength gains were independent of the changes in antagonistic muscle activation.

Because of logistical and technical difficulties, there is a paucity of data on exercise training with an eccentric overload, and the data are equivocal (11,25). Nichols et al. (25) reported superior gains in muscle strength after 12 wk of eccentric overload compared with standard exercise training in elderly adults, but improvements in mobility were independent of training mode. In contrast, Godard et al. (11) reported no significant differences in strength gains after 30 sessions of EO and ST exercise training. One explanation for this latter finding could be that Godard et al. used concentric only test contractions that were insensitive to changes induced by the eccentric overload training. Comparisons between these studies (11,25) and the present work are difficult because of the differences in subject populations, total work, number of repetitions, intensity of exercise, magnitude of eccentric overload, and outcome measures. In a recent study, greater strength gains were observed in the hamstring muscles after short-term training with an eccentric overload compared with conventional loading (19).

To estimate the net effect of eccentric overload, we controlled for total load. This was done to avoid the confounding effects that might have occurred had both total load and the composition of total load been different in EO and ST. However, such a paradigm complicates the interpretation of the magnitude of eccentric overload, as was also the case in the Nichols et al. study (25). Within the EO group, the eccentric phase relative to the concentric phase was overloaded by 50%, but compared with ST, the overload was only about 20%. The reason for the less than 50% between-group eccentric overload is explained by the fewer number of repetitions used by EO to account for the greater eccentric load and equate total work between EO and ST. Nevertheless the present results demonstrate the potency of eccentric contractions for strength gains because, by the most conservative estimates, a mere 20% overload resulted in superior strength after acute (present study) and chronic exercise training (25).

One observation was that exercising at an intensity of about 60% of maximum resulted in marked and rapid gains in maximal strength. For many years the concept has been promoted that low-intensity exercise does not lead to substantial adaptations (2,22). Yet there is now accumulating evidence suggesting that low-intensity exercise does result in substantial changes in maximal muscle strength, muscle fiber size, mobility, and bone mineral density (4,21,29). That lower-intensity exercise may bring about meaningful adaptations is especially relevant for elders, individuals who become deconditioned due to an injury or accident, and the chronically diseased. Exercise intensity as low as 45% has significantly improved 1RM strength in some exercises (25). In addition, we observed that the blood pressure and heart rate responses to one session of EO exercise were about 15% significantly lower compared with the cardiovascular responses to one bout of ST exercise at the same intensity and total work in elderly subjects (17). For how long the strength and cardiovascular benefits would last in either age group is unclear.

Strength gains in previous resistive exercise training studies ranged from 0.5 to 5% per session. In the Nichols et al. study (25), the rate of gain was about 2.8% for the first 2 wk and 1.2% per session over the entire 14-wk period in an elderly group of EO subjects, with less gains in an elderly group of ST. In the Godard et al. study (11), the rate of gain in young subjects was about 4.8% per session over 10 wk. In the present study, the rate of maximal strength gain per session was comparable to the gains in these two studies, 3.8% and 2.6% per session in EO and ST, respectively. We observed significantly greater gains in isometric strength after EO than ST, suggesting that the training adaptations were the result not only of learning but also of improved contractile characteristics, especially in the EO group (27). It is possible that these greater isometric strength gains in EO compared with ST were due to the isometric pause that was used to adjust the weights between the concentric and eccentric phases of the movement. It is also worth noting that the daily loads increased linearly from day to day (Table 1). This linear increase in training volume suggests that the low exercise intensity and the ample rest intervals between exercise bouts prevented overtraining and injury.

It is well established that the initial adaptations to resistive exercise training are neural (28). One form of neural adaptation to exercise is an increased activation of muscle by the nervous system, leading to the prediction of a constant force to EMG ratio. That is, as both EMG activity and muscle force increase, the neural cost of force production is constant. In the present and previous studies (15), we observed changes consistent with this prediction, confirming some earlier data (12) but contradicting other findings (24). The original argument was that muscles become electrically more efficient so that less neural drive is needed to produce the same force (7). In magnetic resonance imaging studies, a smaller amount of muscle was activated after exercise training, and this smaller muscle involvement may result in less EMG activity (26). If muscle strength increases whereas EMG activity is reduced, then exercise nullifies the initial linear relation between force and EMG activity (23). But paradoxically, the EMG to force relationship after many years of exercise training in highly trained athletes is invariably linear (12). These data underscore the complexity of interpreting EMG data in longitudinal studies (5).

Another manifestation of neural adaptation to exercise training is reduced antagonistic muscle coactivity (28). For example, maximal isometric exercise training of the knee extensors over 24 sessions in 8 wk resulted in about 20% reduction in hamstring coactivity (5). In addition, highly strength trained athletes compared with sedentary subjects exhibited smaller semitendinosus coactivity during maximal effort knee extension tasks (1). However, other cross-sectional and longitudinal studies contradict these findings, suggesting that exercise or practice may not modify coactivity. Skilled weight lifters revealed up to 50–60% of maximal EMG activity in the biceps femoris when this muscle acted as the antagonist to the vastus lateralis (10). Hasan (13) argued that in some cases muscle coactivation may actually decrease the effort necessary to perform a movement, and data on skill acquisition seem to support this argument (9). Finally, longitudinal exercise studies using pure eccentric and concentric contractions of arm and leg muscles demonstrated no changes in coactivity (6,15). In line with these latter studies, after 7 d of EO or ST exercise training, we observed no changes in biceps femoris coactivity under isometric, eccentric, or concentric test contractions.

After 7 d of exercise, we observed a 12% statistically not significant reduction in the hamstring to vastus lateralis coactivity ratio. These data are in contrast to the data by Carolan and Cafarelli (5), who observed an actual reduction in hamstring coactivity ~20%. The reduction in the coactivity ratio was driven by the increase in vastus lateralis activity, as the magnitude of coactivity itself did not change. Beyond methodological differences between the current and the prior work (5), we are unable to resolve this discrepancy. Perhaps we would have seen changes in muscle coactivity had we taken EMG measurements during the knee extension movement the subjects used as the training exercise and not under isokinetic or isometric conditions on the dynamometer (28). An alternative interpretation to the expected reduction in coactivity after exercise training could be that increased force production by the agonists must be balanced by the antagonists to maintain appropriate joint stability and stiffness (3).

In conclusion, acute quadriceps exercise training with an eccentric overload resulted in about twofold greater gains in muscle strength compared with exercise composed of a conventional loading pattern. These strength gains were paralleled by changes in EMG activity, leading to unaltered force to EMG ratios. The strength gains were independent of muscle coactivity. Because the strength gains were achieved by exercising at low intensities and over a short time period, exercise prescription of eccentric overloading appears especially suitable for elders, individuals deconditioned due to an injury, and the chronically diseased.

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