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Power training is more effective than strength training for maintaining bone mineral density in postmenopausal women

**S. V. Stengel,[1] W. Kemmler,[1] R. Pintag,[1] C. Beeskow,[1]
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Stengel, S. V., W. Kemmler, R. Pintag, C. Beeskow, J. Weineck, D. Lauber, W. A. Kalender, and K. Engelke. Power training is more effective than strength training for maintaining bone mineral density in postmenopausal women. *J Appl Physiol* 99: 181–188, 2005. First published March 3, 2005; doi:10.1152/japplphysiol.01260.2004.—Physical exercise has a favorable impact on bones, but optimum training strategies are still under discussion. In this study, we compared the effect of slow and fast resistance exercises on various osteodensitometric parameters. Fifty-three postmenopausal women were randomly assigned to a strength training (ST) or a power training group (PT). Both groups carried out a progressive resistance training, a gymnastics session, and a home training over a period of 12 mo. During the resistance training, the ST group used slow and the PT group fast movements; otherwise there were no training differences. All subjects were supplemented with Ca and vitamin D. At baseline and after 12 mo, bone mineral density (BMD) was measured at the lumbar spine, proximal femur, and distal forearm by dual-energy X-ray absorptiometry. We also measured anthropometric data and maximum static strength. Frequency and grade of pain were assessed by questionnaire. After 12 mo, significant between-group differences were observed for BMD at the lumbar spine ($P < 0.05$) and the total hip ($P < 0.05$). Whereas the PT group maintained BMD at the spine (+0.7 ± 2.1%, not significant) and the total hip (0.0 ± 1.7%, not significant), the ST group lost significantly at both sites (spine: −0.9 ± 1.9%; $P < 0.05$; total hip: −1.2 ± 1.5%; $P < 0.01$). No significant between-group differences were observed for anthropometric data, maximum strength, BMD of the forearm, or frequency and grade of pain. These findings suggest that power training is more effective than strength training in reducing bone loss in postmenopausal women.

exercise; resistance training; osteoporosis

RECENT META-ANALYSES OF LONGITUDINAL studies confirmed that exercise has a positive influence on the skeleton and increases or, in more elderly subjects, maintains bone mineral density (BMD) (26, 27, 60, 62). Although optimum training strategies are still under discussion, it is generally acknowledged that the training should be population specific. For example, exercises that were highly effective in premenopausal women did not show a major impact on bone after menopause (5, 49). Cross-sectional studies with athletes demonstrated that BMD was strongly associated with high-impact load-bearing activities, such as sports games or gymnastics (12, 34, 37, 40). BMD was also highly associated with activities that required high muscular tension such as weight lifting (17, 18, 37, 39).

To develop an effective exercise program, it is important to understand the interaction between exercise and bone turnover and formation. Data on this subject are still rare, but the dose-response relationship of isolated mechanical loading parameters has been investigated in several in vivo loading studies of animal bones. Various models such as the functionally isolated avian ulna (44), four-point bending of the rat tibia (53), axial loading of the rat ulna (51), and models of ground-based vibrations (42, 43) have been applied successfully. Typical end points are histomorphometric parameters of bone formation. These studies show that strain magnitude, strain rate, cycle number, strain frequency, strain distribution, and rest periods are associated with osteogenic impact.

Many results based on animal studies can be integrated in human exercise regimen (8, 22), but this has rarely been done (41, 58). Furthermore, studies that compared the effects of mechanical parameters on BMD in humans almost exclusively focused on strain magnitude. This parameter was predominantly investigated in studies comparing the effect of low- vs. high-intensity resistance training (4, 6, 32, 33, 35, 59). Only one study specifically investigated the effect of strain rate (4). The study showed that high-impact (jumping) exercises were significantly more efficient than low-impact exercises. The positive effect of a high strain rate on BMD was confirmed indirectly by several other studies (1, 5, 16, 49).

In our study, we also focused on strain rate. Our major hypothesis is based on the assumption that high-velocity resistance training (power training) results in more pronounced stimuli than low-velocity resistance training (strength training) and should be more effective in maintaining bone density in postmenopausal women. In our 2-year program for which we report first-year results, we included pretrained women who had participated in the training arm of the Erlangen fitness osteoporosis prevention study (EFOPS) for 3 years (29, 31).

MATERIALS AND METHODS

The present study was approved as an extension of the EFOPS study by the ethics committee of the University of Erlangen (Ethik Antrag 905, S9108-202/97/1, S21-22112-81-00) and the German and Bavarian radiation safety agencies (Bundesamt für Strahlenschutz: Z2.1.2-22462/2-2002-016 and Bayerisches Landesamt für Arbeitssicherheit: 13B/3443-4/5/98). All study participants gave written, informed consent.

Subjects

Fifty-three osteopenic postmenopausal women (4–11 yr postmenopause) were included in the study. These women had participated in the training arm of the EFOPS study for 3 years before start of the study. None of the subjects had a disease or used medication affecting

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bone metabolism. The subjects were groupwise randomly assigned to a strength ($n = 28$) or a power training program ($n = 25$).

Exercise Program

Both groups carried out the following weekly training program: two weight-lifting sessions (60 min each), one gymnastic session (60 min), and one home training session (25 min) with at least 1 day of rest between the joint exercise sessions. Attendance was assessed every 12 wk by using subject-specific training logs as well as attendance lists kept by the trainers.

Weight-lifting session. The weight-lifting session started with a 20-min warm-up (running, low-/high-impact aerobics at 70–85% maximum heart rate), followed by a jumping sequence with 4 × 15 multidirectional jumps. Machines for multijoint exercises (Technogym, Gambettola, Italy) were used for horizontal leg press, leg curls, bench press, rowing, leg adduction and abduction, abdominal flexion, back extension, lat pulley, hyperextension, leg extension, shoulder raises, and hip flexion.

Twelve-week intervals of periodized high-intensity training [70–90% 1-repetition maximum (1 RM)] were intermitted with 4–5 wk of lower training intensity (50% 1 RM). The only difference between the two groups was the movement velocity. The training protocol specified a 4-s concentric, 4-s eccentric sequence in the strength training group (ST) and a concentric fast/explosive, 4-s eccentric sequence in the power training group (PT).

Gymnastics session. The objective of the gymnastics program was to improve fall-related abilities. It consisted of coordination, strength, endurance, and flexibility training.

Home training session. All participants were requested to carry out a 25-min home training session once a week with rope skipping, stretching, isometric exercises, and exercises with rubber bands.

Power vs. strength training. Six months after study start, when the participants were accustomed to the training scheme, ground reaction forces were measured with a force plate (mtd-Systems, Neuburg v. Wald, Germany) mounted on the leg press machine. In a subset of the participants (PT: $n = 16$, ST: $n = 18$), force-time curves were recorded over a period of six repetitions carried out with loads corresponding to ~75% 1 RM. Relative loading magnitude and amplitude, loading frequency, and maximum loading and unloading rates were extracted from the curves and used to compare power and strength training.

The relative loading magnitude (given in %) was calculated by normalizing the average of the six force maxima (Fig. 1) with the lifted weight. The relative loading amplitude was determined in the same way by using the differences between maxima and minima. Maximum loading and unloading rates (N/ms) were determined from the derivatives (Fig. 2) of the smoothed force-time curves, again by averaging the results from the six repetitions.

The frequency spectrum or loading distribution was determined by a fast Fourier transform of the force-time curve, which decomposes the signal into its sinusoidal components, providing a force-vs.-frequency-graph (Fig. 3). For the statistical analysis, the frequency spectrum was divided into six intervals of 0.5 Hz each, covering 0 to 3 Hz. Finally, a Fourier synthesis was performed to analyze the contribution of each 0.5-Hz interval to the total frequency bandwidth of the original signal.

Figure 1 shows characteristic force-time curves of strength (*A*) and power training (*B*). Owing to the fact that during strength training the velocities are small, the force increases and decreases more or less continuously. In contrast, during power training, each repetition shows "double peak" behavior. The large peak can be attributed to the first phase of the explosive leg extension, when pushing the weight forward and pausing in a short unloading phase. Then the force is increased again, resulting in a second peak that is usually lower than the first. The loading rates can directly be obtained from the derivatives of the force-time curves and are shown in Fig. 2.

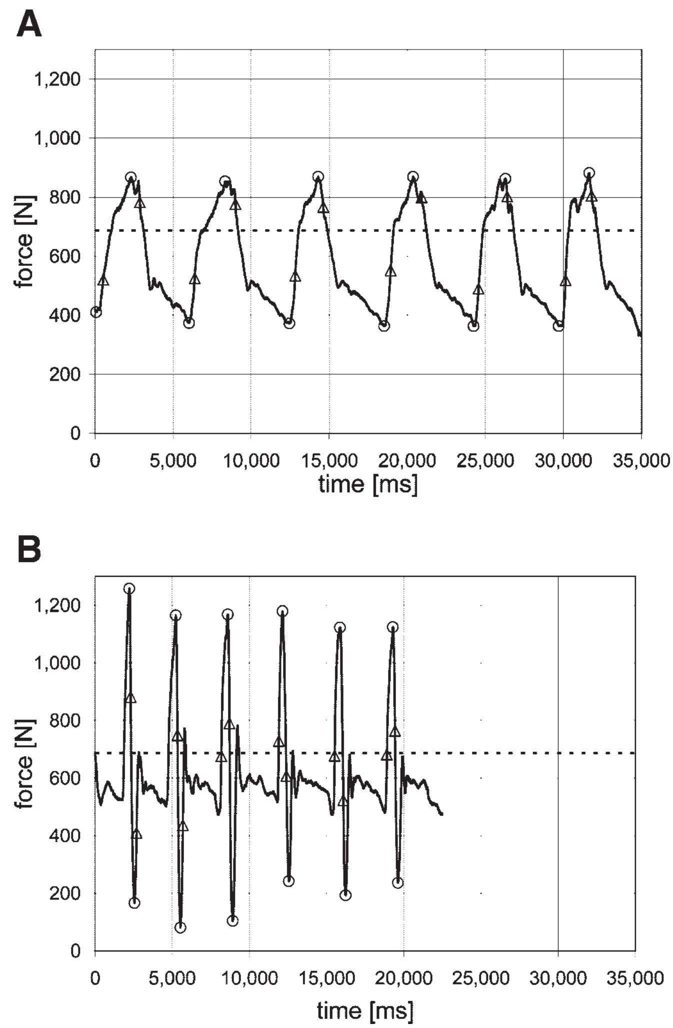

Fig. 1. Characteristic force-time curves for strength training (*A*) and power training (*B*). For each of the 6 repetitions, maximum and minimum loading forces are marked by circles. Maximum loading and unloading rates are determined in the derivatives (Fig. 2) and are marked by triangles. The dashed line indicates the subject's specific force of gravity (weight multiplied by 9.81).

Quantitative results of group differences are displayed in Table 1. Differences range from 16% for the relative loading magnitude to 611% for the unloading rate. Table 2 and Fig. 4 display the results from the Fourier synthesis. In the ST group, low frequencies up to 1 Hz account for 86% of the total signal strength, whereas the frequency distribution in the PT group extends to higher frequencies. 27.4% of the total strength is associated with frequencies beyond 2 Hz compared with only 6.6% in the ST group.

Compared with the specified training protocols, both groups carried out the leg press exercise at higher speed. In the example shown in Fig. 1, the slow movement took 5.8 instead of 8 s and the fast movement only 3.8 s. Average values were 5.6 ± 0.8 s in the ST and 3.5 ± 0.6 s in the PT group.

Ca and Vitamin D Supplementation

Depending on the individual Ca and vitamin D (Vit-D) intakes, each participant received supplemental Ca and Vit-D to ensure a total daily intake of 1,500 mg Ca and 500 IE Vit-D (28). The individual dietary intake was assessed with a 5-day protocol. The consumed food was weighed precisely. The analysis of the protocols was performed

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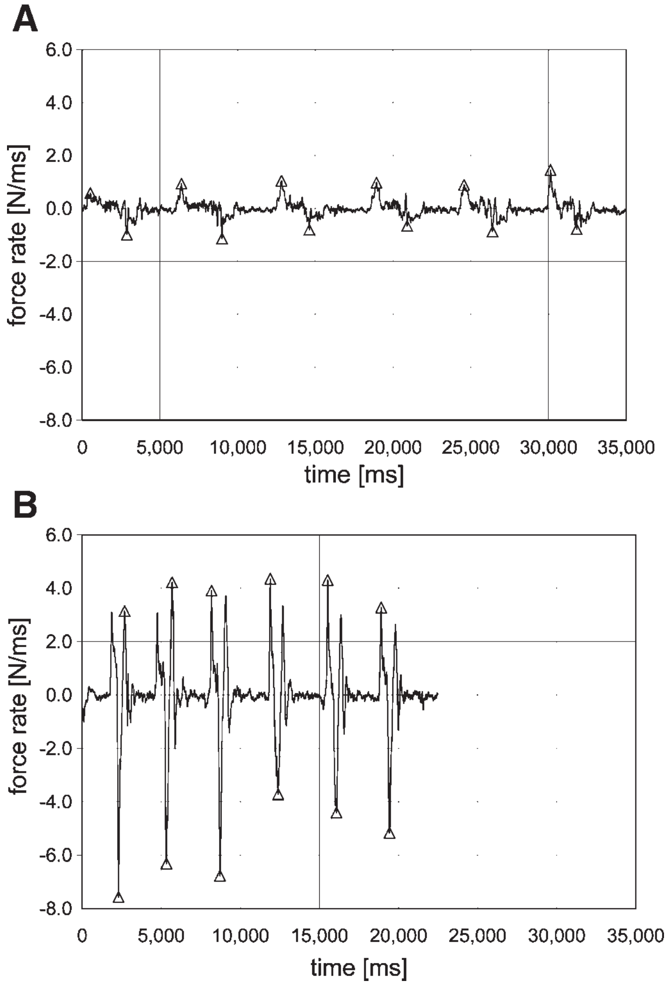

Fig. 2. Derivatives of Fig. 1 showing the maximum loading and unloading rates for strength (*A*) and power training (*B*).

using Prodi-4,5/03 Expert software (Wissenschaftlicher Verlag, Freiburg, Germany).

Measurements

For each study subject, the measurements described in the following sections were carried out at baseline and repeated after 12 mo. The measurements can be grouped into four blocks: anthropometry, bone densitometry, exercise, and pain.

Anthropometry. We measured height, weight, and body composition (percent body fat, lean body mass, total body water). Body composition was assessed with the impedance technique (Tanita BF 305, Tanita, Japan).

Bone densitometry. Bone mineral density was measured by dual-energy X-ray absorptiometry (QDR 4500A, Hologic, Bedford, MA) at the lumbar spine (L1–L4), the proximal femur, and the distal forearm by use of standard protocols.

Exercise tests. Maximum isometric strength values of the trunk extensors and flexors, the hip flexors, the leg adductors and abductors, and the arm flexors and extensors were determined isometrically by use of a Schnell-Trainer dynamometer and a Schnell M-3 isometric tester (Schnell, Peutenhausen, Germany) following Tusker's protocol (57). Strength was recorded as the product of force and lever arm in Newton-meters (N·m).

At baseline, endurance was measured by a stepwise treadmill test up to voluntary maximum. Starting with 6 km/h (0° slope), the velocity was increased every 3 min by 1 km/h. Minute ventilation,

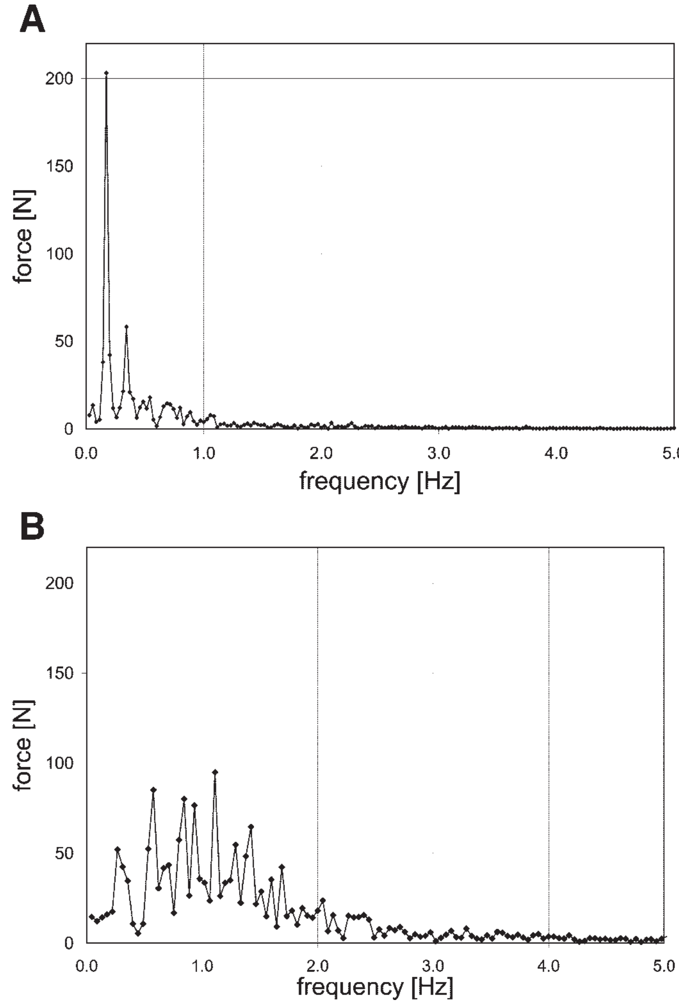

Fig. 3. Frequency distribution of strength (*A*) and power training (*B*) derived form a Fourier transform of the force-time curves in Fig. 1.

maximal O_2 uptake, and maximal CO_2 production were determined by using a Zan 600 open spirometric system (Zan, Oberthulba, Germany). All subjects achieved a minimum maximal heart rate of 155 min^{-1}. This measurement was not repeated after 12 mo.

Pain. Pain frequency and intensity at various skeletal sites were assessed by questionnaires according to Jensen (21) and the Osteoporosis Quality of Life Study Group (35a). The reproducibility of the questionnaires had been evaluated in an earlier study (30). A random sample of 10 women had answered the questionnaires twice within 2

Table 1. *Characteristic group differences of strength vs. power training for mechanical loading parameters*

	ST (n = 16)	PT (n = 18)	Difference [%]	P
Relative loading magnitude, %	121.5±5.9	140.8±15.7	15.9	<0.001
Relative loading amplitude, %	61.5±6.8	112.2±24.3	82.3	<0.001
Loading rate, N/s	1414±330	5125±1946	262	<0.001
Unloading rate, N/s	−1157±383	−8232±3548	611	<0.001

Values are means ± SD. ST, strength training group; PT, power training group.

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Table 2. *Results of the Fourier synthesis (see text): contribution of frequency intervals to the total force signal*

Frequency Interval, Hz	Contribution to Total Signal, % ST (n = 16)	PT (n = 18)	*P*
0–0.5	74.0±5.9	13.2±5.4	<0.001
0.5–1.0	11.8±4.0	20.0±7.0	<0.001
1.0–1.5	5.1±1.7	23.6±7.0	<0.001
1.5–2.0	2.5±1.0	15.8±4.1	<0.001
2.0–2.5	1.3±0.4	12.2±4.6	<0.001
2.5–3.0	0.8±0.3	3.8±2.5	<0.001

Values are means ± SD.

wk. The mean difference between the first and the second score was less than 5%.

Statistical Analysis

Unless stated otherwise, all measured values are reported as means and standard deviations. The Kolgomorov-Smirnov test was used to check for normal distributions; Levine's *F*-test was used to check for homogeneity of variance. In the analysis, we evaluated the training effect on bone, that is, we used all densitometric parameters as dependent variables. Specifically, the following questions were investigated: *1*) Were groups comparable at baseline? Here unpaired *t*-tests for normally distributed variables and Mann-Whitney *U*-tests for not normally distributed variables were applied. *2*) Was the power training more effective than the strength training? Here we used a two-way ANOVA with repeated measures. The within-group factor was time (baseline vs. 12 mo), and the between-group factor was type of training (PT vs. ST). *3*) Were within-group changes between baseline and follow-up significantly different from zero? For this purpose, paired *t*-tests or Wilcoxon tests were used.

All three analysis steps were carried out twice. First, we excluded subjects with insufficient training frequency (<2 joint sessions/wk averaged over the 12-mo period). Then we repeated the analysis independent of training frequency. All tests were two tailed, and a 5% probability level was considered significant (*). We used SPSS 12.0 (SPSS, Chicago, IL) for statistical analysis. The fast Fourier transformation and the spectral analysis of the force-time curves were carried out in EXCEL 2003 (Microsoft).

RESULTS

All 53 enrolled study subjects completed the first study year. However, two subjects of the ST group were excluded from all analyses because they took medications (glucocorticoids) or had acquired diseases (hyperparathyroidism) affecting bone metabolism. Another nine subjects (PT: n = 4; ST: n = 5) were in the category "insufficient training frequency." Thus, in the first analysis, 21 women of the ST and 21 women of the PT group were included in the 12-mo analysis. The important parameters describing the two training regimens have been described and analyzed in MATERIALS AND METHODS. There were no significant differences in the weekly training attendance rates between the ST (2.48 ± 0.31 sessions) and the PT (2.43 ± 0.32 sessions) groups.

Table 3 lists baseline data for nondensitometric parameters and Table 4 includes the baseline data for densitometric parameters. None of the nondensitometric parameters showed significant between-group differences. Furthermore, at baseline there were no differences in maximum static strength at any skeletal region. Average BMD values at the spine and hip tended to be lower in the PT group, yet those at the forearm tended to be higher. However, levels of significance were only achieved in the forearm and the intertrochanteric regions.

When using the two-way ANOVA, all between-group differences for height, weight, lean body mass, percent body fat, total body water, and for maximum isometric strength and endurance were nonsignificant after 12 mo. This result was independent of whether subjects with insufficient training frequency were excluded.

Training Effects on Osteodensitometric Parameters

Table 4 displays baseline and 12-mo values for the densitometric parameters. Here, subjects with insufficient training frequency were excluded. After one year, power training resulted in larger effects than strength training at the lumbar spine, total hip, and intertrochanter. For the trochanter, differences of the training effects were almost significantly different (Fig. 5). Corresponding *F* and *P* values of the time × training group interaction term, resulting from the ANOVA, are shown in Table 4. For the hip, within-group *t*-tests showed significant BMD losses for all regions in the ST group and stable BMD in the PT group.

Corresponding relative changes (%) in the ST group were as follows: LS, −0.9 ± 1.9; total hip, −1.2 ± 1.5**; femoral neck, −1.6 ± 2.5**; trochanter, −0.9 ± 2.2*; intertrochanter, −1.4 ± 3.0**; total forearm, −0.2 ± 1.3; and ultradistal radius: −0.5 ± 3.1. Relative changes in the PT group were LS, +0.7 ± 2.1; total hip, 0.0 ± 1.7; femoral neck, −0.4 ± 2.8; trochanter, 0.2 ± 2.3; intertrochanter, 0.1 ± 2.9; total forearm, −1.0 ± 1.4**; and ultradistal radius, −0.5 ± 2.9. The levels of significance indicate whether the changes were different from zero.

When inadequate training frequency was not an exclusion criterion, there were no principal changes in the ANOVA results for the time × training group interaction term. However, with the exception of the lumbar spine, significance levels were lower (LS: F = 11.63, P = 0.001; total hip: F = 4.26, P = 0.044; trochanter: F = 3.11, P = 0.084; intertrochanter: F = 5.11, P = 0.028). All insignificant between-group differences remained insignificant.

Pain

With exception of the neck, there were no between-group differences with respect to changes in pain frequency or grade

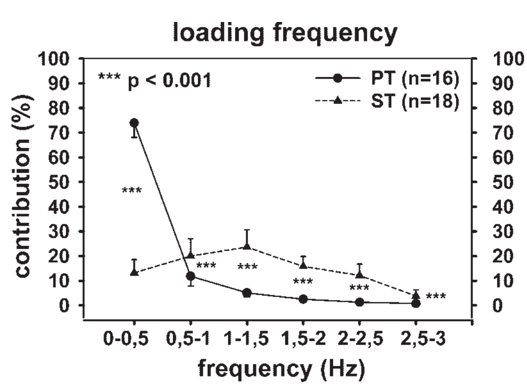

Fig. 4. Contribution of the 6 frequency bins to the total signal. PT, power training group; ST, strength training group.

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Table 3. *Baseline data of study subjects included in the analysis*

	PT (*n* = 21)	ST (*n* = 21)	Difference
Age, yr	57.7±3.2	57.6±3.0	n.s.
Height, cm	164.0±6.1	162.7±6.7	n.s.
Weight, kg	68.5±7.7	64.3±9.2	n.s.
BMI, kg/m^2	25.5±3.3	24.3±4.4	n.s.
Body fat, %	35.4±5.8	33.8±6.1	n.s.
LBM, kg	43.9±3.1	42.3±4.8	n.s.
Waist/hip index	0.82±0.04	0.81±0.05	n.s.
Maximum grip strength, kg	30.76±3.97	31.14±4.72	n.s.
Maximum strength body flexion, Nm	72.76±15.65	77.52±17.59	n.s.
Maximum strength back extention, Nm	131.90±25.27	133.19±29.76	n.s.
Maximum strength leg addution, Nm	120.24±21.01	120.29±19.28	n.s.
Maximum strength leg abduction, Nm	94.10±17.53	88.95±18.63	n.s.
Maximum strength arm flexion, Nm	78.81±10.82	85.19±16.81	n.s.
Maximum strength arm extention, Nm	68.86±12.23	69.67±10.22	n.s.
Maximal oxygen consumption, l/min	2.01±0.23	1.98±0.29	n.s.
Energy intake, kJ/day*	8,848±1,111	8,861±1,501	n.s.
Protein intake, g/day*	72.4±12.8	68.9±12.2	n.s.
Calcium intake, mg/day*	1219±417	1235±415	n.s.
Phosphor intake, mg/day*	1484±259	1450±349	n.s.
Vitamin D intake, μg/day*	4.9±3.8	4.5±3.9	n.s.
Osteoporosis in the family, %/group	19%	14%	n.s.
Coffee consumption, ml/day*	701±394	705±388	n.s.
Smoker, %/group	10%	10%	n.s.

Values are means ± SD. BMI, body mass index; LBM, lean body mass; n.s., not significant. *Data from 5-day dietary records.

for any of the skeletal sites assessed (big joints, small joints, neck, and lower and upper back). In the neck, pain intensity was constant in the ST group but decreased in the PT group. Within-group changes were significant for pain frequency in the big joints in the PT group. Figure 6 shows results for the lower back and the big joints (hip, knee, shoulder), which are of special interest.

DISCUSSION

Embedded in a high-impact loading and aerobic exercise program, we investigated the effect of different training velocities in the strength training sequence. We specifically modified the velocity of the concentric movements during the machine training. Our analysis of the force-time curves shows that weight-adjusted loading magnitudes and amplitudes, and strain rates and frequencies, were significantly increased in the PT group carrying out the fast movements. Animal studies (19, 24, 25, 38, 45, 54–56) have shown that each of the four parameters has an osteogenic impact, but their combined effect has not been investigated. In our study, we focused on this issue by an increase of training velocity that impacted simultaneously on loading magnitudes and amplitudes, and on strain rates and frequencies.

Which parameter is most important when applied in combination is not clear yet. From experiments in roosters, Judex and Zernicke (24, 25), who had determined strain magnitudes and rates with strain gauges in vivo, concluded that strain rate was more important than strain magnitude. In two studies, they had compared the effects of low-impact (walking and treadmill running) and high-impact (drop jumps) exercises at the tarsometatarsus. Drop jumps increased peak strain magnitudes only moderately by +30% (relative to walking) and +11% (relative to running) but produced much higher strain rates of +740% and +256%, respectively. After 3 wk with 200 jumps daily, bone formation rates significantly increased periostally (+40%) and endocortically (+370%) whereas treadmill running did not increase bone formation. As determined in a rat ulna loading model, reported by Skerry and Peet (47), loading and unloading rates have similar osteogenic impacts. Therefore, in our study, the large difference in the loading rates and, in particular, the unloading rates may be essential for the superiority of the power training approach.

Models that regard fluid flow as the central mechanism for the stimulation of bone adaptation (7, 9, 48, 54, 61) suggest that the loading amplitude, which in our study was 82% higher in the PT compared with the ST group, should also play an important role. Furthermore, Turner et al. (54) showed that in the range between 0.2 and 2.0 Hz a higher loading frequency was associated with a higher osteogenic response. In our study, most loading frequencies ranged from 0.2 to 1.0 Hz in the ST and up to 2.5 Hz in the PT group.

In accordance with the animal studies summarized above, we observed significantly higher antiresorptive effects in the PT compared with the ST group (see Table 4 and Fig. 5), although the follow-up time of our study of 1 year was short and the number of subjects was relatively small. Even when

Table 4. *Results for osteodensitometric parameters*

Variable	Strength Training Group (*n* = 21) Baseline	Strength Training Group (*n* = 21) Year 1	Power Training Group (*n* = 21) Baseline	Power Training Group (*n* = 21) Year 1	ANOVA Interaction Term *F*	ANOVA Interaction Term *P*
DXA lumbar spine, g/cm^2	0.884±0.083	0.876±0.078	0.867±0.069	0.873±0.081	5.564	0.023
DXA lumbar spine area, cm^2	61.18±4.99	60.90±5.19	60.63±5.19	60.80±5.60	1.366	0.249
DXA total hip, g/cm^2	0.858±0.094	0.848±0.094	0.834±0.045	0.834±0.042	6.416	0.015
DXA femoral neck, g/cm^2	0.705±0.065	0.694±0.068	0.703±0.059	0.700±0.054	1.281	0.264
DXA trochanter, g/cm^2	0.670±0.096	0.664±0.093	0.623±0.048	0.624±0.049	3.933	0.054
DXA intertrochanter, g/cm^2	1.020±0.128	1.006±0.126	0.997±0.064†	0.998±0.065	7.373	0.010
DXA total forearm, g/cm^2	0.502±0.046	0.501±0.046	0.523±0.039*	0.518±0.039	3.402	0.730
DXA ultradistal radius, g/cm^2	0.390±0.057	0.388±0.056	0.414±0.043*	0.412±0.044	0.001	0.980

Values are means ± SD. *Columns 2–5* show the absolute values at baseline and after *year 1.* Significant between-group differences at baseline are marked in the power training group: $*P < 0.05$, $†P < 0.01$. *Columns 6* and *7* show *F* and *P* values of the interaction term of time and training type from the 2-way ANOVA. The critical $F(1,40)$ value ($\alpha = 0.05$) is 4.08. The data shown apply to the groups in which subjects with insufficient training frequencies were excluded.

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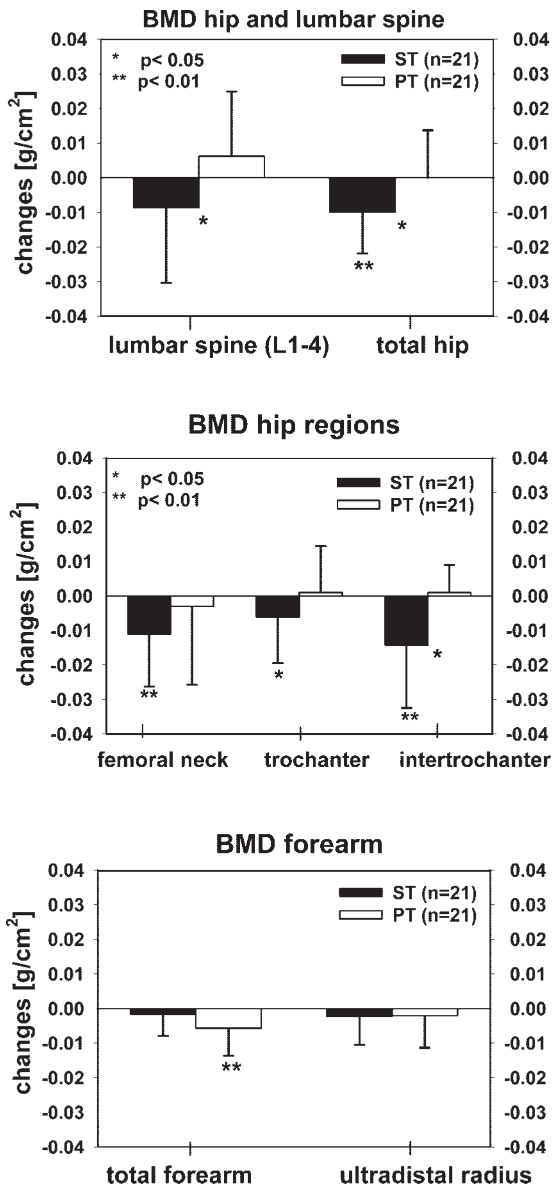

Fig. 5. Absolute changes of dual-energy X-ray absorptiometry measurements between baseline and *year 1*. Between- and within-group levels of significance are shown. Between-group levels resulted from ANOVA, within-group levels from paired *t*-tests. BMD, bone mineral density.

subjects with low training frequency were not excluded, the effect was maintained, although lower in magnitude. Our group was too small to investigate a dose-response relationship; nevertheless we recommend higher (>2 joint sessions/wk) training frequencies.

Similar to the EFOPS training period (29, 31) preceding this study, there were no significant group differences at the distal forearm. Of course, this may also be attributed to the limitations in study design mentioned above. However, because of the EFOPS results, in which a significant BMD decrease of 3.5–4.0% was observed in the training group, we now believe that our specific forearm exercises (lat pulley, rowing, and bench press) are less effective compared with the exercises applied to the other skeletal sites. Actually, only bench press exercises result in a direct compression of the distal forearm, whereas the other two exercises cause tension. In line with this observation, a protocol with substantially higher loading variations generated by bending, tension, torsion, and compression demonstrated significant exercise effects on BMD of the distal radius (33, 46).

One may argue that a direct comparison between loading studies in animals and exercise studies in humans is problematic. In animals, the strains applied to bone can be measured directly, whereas in humans only the surrogate measurement of external forces is possible. However, in favor of the contrary, Bassey and colleagues (3) found that at the proximal femur peak ground reaction forces as well as force rates of different activities (walking, jogging, jumping) significantly correlated with internal forces measured by a specially equipped hip implant. Also within physiological loading ranges, forces are directly proportional to strains exerted on bone (22). Thus it seems likely that the mechanical parameters that we determined are comparable to the strain parameters in animal studies. Therefore, general conclusions drawn from animal models should be transferable to humans, even if direct strains are usually not assessable.

Power training, characterized by explosive muscle contraction, produces higher stresses on tendons and joints than strength training. Therefore, as a measure of precaution, in recreational sports activities, slow movements are recommended for weight lifting exercises to minimize injuries. This particularly applies to elderly subjects, whose adaptability to intensive stimuli might be reduced (11). However, with the exception of pain intensity at the neck, we did not observe

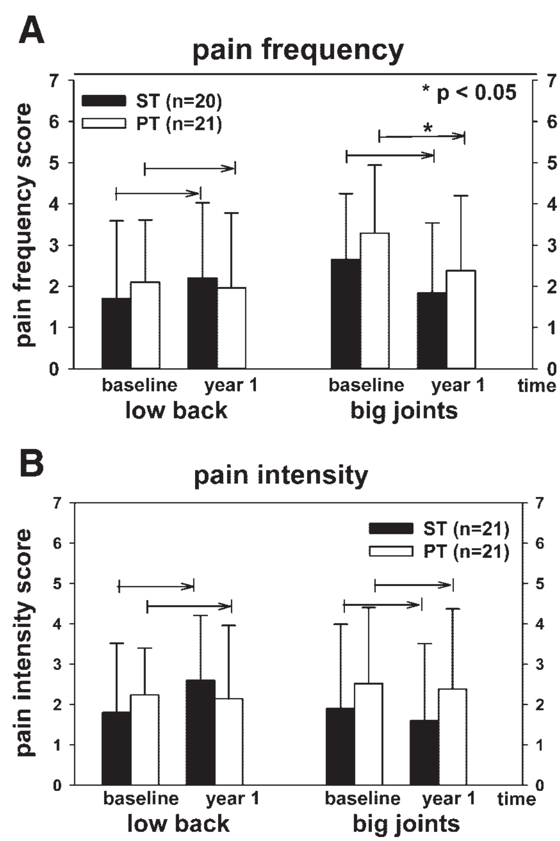

Fig. 6. Pain frequency (*A*) and intensity (*B*) of the lower back and the main joints at baseline and after *year 1*.

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significant pain intensity- or pain frequency-related differences between the PT and the ST group at any skeletal site. There was a trend toward pain frequency reduction in the big joints in both groups that was significant at the $P < 0.05$ level in the PT group. We attribute these results to the 3-year EFOPS training preceding this study. During that period, weight-lifting exercises with moderate (2-s concentric, 1-s static, 2-s eccentric) velocities were carried out. Thus the subjects randomized to power training were well trained and already adapted to heavy loading. At the EFOPS baseline, there were also no significant differences between the ST and the PT groups (data not shown here).

Furthermore, the periodized training design with 12 wk of high-intensity training (70–90% 1 RM), interleaved by 4–5 wk of lower training intensity (50% 1 RM) provided ample time for regeneration. Therefore, with an adequate training regimen, the maintenance of bone density does not necessarily conflict with increased pain. This contradicts earlier arguments (52). Nevertheless, we do not claim that for elderly subjects power training is generally unproblematic. In particular, long-term effects in the elderly are yet unknown because none of the studies investigating this question exceeded 6 mo (10, 13–15, 36). On the other hand, some studies suggest that muscle power is an essential component of functional mobility in elderly people (2, 23, 36, 50) and that power training might be at least as important as strength training (36). It would be interesting to know whether our results could be repeated in sedentary women, and a corresponding study should be carried out.

In summary, this contribution clearly demonstrates the superiority of power vs. strength training on BMD at the lumbar spine and the proximal femur. It also demonstrates that our power training approach with postmenopausal women did not increase pain. These findings highlight the importance and feasibility of power training and encourage its incorporation in training programs for the elderly, although its use and impact on pain in untrained women requires further validation.

Further research should be undertaken to quantify the exercise-induced mechanical milieu that is associated with different physical and sportive activities to identify those mechanical parameters that trigger the modeling and remodeling process. With this knowledge, the optimization of exercise programs would be much easier.

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