EFFECTS OF 26 WEEKS PLYOMETRIC AND DYNAMIC STRENGTH TRAINING AND ESTROGEN REPLACEMENT THERAPY ON ISOMETRIC MUSCLE STRENGTH OF POSTMENOPAUSAL WOMEN

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ABSTRACT

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The effects of 26 weeks of estrogen replacement therapy and plyometric and dynamic strength training on isometric strength of knee extensor, elbow flexor and hand grip were studied in 80 postmenopausal women. The estrogen replacement therapy was administered on a doubleblind basis, and the women were split into four groups after baseline tests: exercise, exercise with estrogen, estrogen, and control group. The strength tests were done on a dominant side. The participation rate of the training was on average 71%. The percent body fat decreased significantly in the exercise with estrogen group compared to controls. There was a significant interaction of group by time in the knee extension force ($p = 0.043$), torque ($p = 0.016$) and torque related to body mass ($p = 0.011$). The changes in knee extension force and torque were significantly greater in all three experimental groups when compared to the controls. The knee extension force levels during 200-500 ms also increased in the study groups ($p < 0.001$). The isometric elbow flexion showed an increase that was statistically significant in exercise and in estrogen groups compared to controls. The force production of elbow flexion increased with statistical significance ($p < 0.05$) during 300-500 ms in other study groups except in the control group. The hand grip force did not change significantly after 26 weeks of exercise and estrogen replacement therapy. The force production of hand grip in all study groups increased significantly during the first 100 ms to 200 ms ($p < 0.005$) and at 300 ms ($p = 0.03$). The physical activity of the study groups increased significantly during the 26 weeks when the exercise intervention was left out of the calculation. The results showed, that postmenopausal women tolerate plyometric and dynamic strength training well, and that isometric knee extension and elbow flexion force can be increased by plyometric and dynamic strength training. The strength gain is also increased by estrogen replacement therapy.

Keywords: postmenopause; plyometric training; strength training; isometric strength; estrogen

CONTENTS

1 INTRODUCTION....4
2 LITERATURE REVIEW....5
2.1 Muscle strength....5
2.1.1 Different forms of muscle action....5
2.1.2 Maximal strength....6
2.1.3 The force-velocity curve....7
2.2 Effects of strength training....8
2.2.1 Plyometric training....10
2.3 Isometric strength testing....11
2.4 Postmenopause and estrogen hormone....12
2.4.1 Postmenopausal female status in relation to strength training....13
2.4.2 Anthropometry....14
3 STUDY AIMS....15
4 MATERIAL AND METHODS....16
4.1 Subjects....16
4.2 Estrogen replacement....16
4.3 Exercise intervention....17
4.3.1 The circuit training routine....17
4.3.2 The home exercise program....19
4.3.3 The training diaries....19
4.4 Measurements....20
4.4.1 Anthropometry....20
4.4.2 Isometric musclestrength....20
4.3.3 The test protocol of isometric strength testing....21
4.5 Statistical analysis....23
5 RESULTS....24
5.1 The level of exercising and the compliance with the study....24
5.1.1 The home training diaries....24
5.1.2 The supervised circuit training....26
5.2 Anthropometry....28
5.3 Knee extensor strength....29
5.4 Hand grip and elbow flexor strength....32
6 DISCUSSION....37
7 TIIVISTELMÄ....41
8 REFERENCES....42
9 APPENDIXES....47
Appendix 1. The supervised circuit training diary....48
Appendix 2. The home training diary....52

1 INTRODUCTION

Life expectancy has increased significantly in our society resulting in an expanding of middle-age and elder population. This is the population which actively takes part in different forms of social, political, and recreational life. The current middle-aged population is going to be elderly within the next 10 to 30 years. We are faced with some new but rapidly expanding problems and considerations about their health, independence and quality of life.

There is a increased need for persons interested in rehabilitative physical activity of women to increase their efforts to further understand of the development and prevention of age- as well gender-related and neuromuscular function deficiencies. Women are faced with a large quantity of information about the changes in their body during menopause. One of the items of most concern is osteoporosis.

By knowing the effects and benefits of different forms of physical activity one can choose the mode to suit for his/her purposes. Epidemiological, clinical and experimental exercise studies indicate that physical activity is effective in improving and maintaining muscle strength and endurance (i.e. Hamdorf et al. 1993, Laforest et al. 1990, Pyka et al. 1994, Sipilä & Suominen 1994, Sipilä et al. 1996). The type, intensity, frequency and duration of exercise provide an increase in muscle strength among middle-aged women. The effects on postmenopausal women still remain unknown (Charette et al. 1991, Heislein et al. 1994). These variables can be included in various sports and exercise modalities.

The effects of estrogen replacement therapy on muscle strength of postmenopausal women is controversial. Some have found no effect on muscle strength (Taaffe et al. 1995) when others did (Cauley et al. 1987, Heikkinen et al. 1997). By simultaneous intervention of estrogen and exercise these regimens can be studied. This will further clarify the effects of estrogen on postmenopause.

When the study "Estrogen replacement and exercise" was introduced me, I found it provided me with a way in which to try and find out if plyometric and strength training might be useful while enhancing the strength of middle-aged women. Many of the studies, like Charette et al. (1991), Kriska et al. (1986), Lexell et al. (1995), Pyka et al. (1994) and Sipilä et al. (1996) have been concerned more with older women, traditional strength training or some other modified version of strength training. Plyometrics, the jumping drills which utilize the body mass of the subject, to produce a speed power training effect, have not been used with middle-aged women, even though it is a well known and used method of strength training among athletes. Plyometrics have the benefit of being easy to do and the only equipment needed are shoes and a solid surface to jump on.

The question; "How plyometric training alters the maximal isometric strength of postmenopausal women?" remains unanswered. Could this training regime be used widely for increasing lower leg strength of middle-age women? These questions I will try to answer.

This study was carried out as a part of the larger research program on exercise and estrogen replacement therapy at the Department of Health Sciences at University of Jyväskylä during the Autumn 1996 and Spring 1997.

2 LITERATURE REVIEW

2.1 Muscle strength

Muscle strength is dependent on the size or volume of the muscle and neural factors. Human skeletal muscle contains two different main types of muscle fibres. These are traditionally classified by ATPase staining as slow twitch (Type I), fast twitch oxidative (Type IIa), fast twitch glycolytic (Type IIb) fibers and a rare and undifferentiated fiber that may be involved in reinnervation or motor unit transformation (Type IIc) (Frontera & Meredith 1989, McArdle et al. 1996, 330-331). According to myosin molecular studies, human skeletal muscle does not seem to contain Type IIb isoforms. The Type IIx has been identified to exist in human skeletal muscle instead of Type IIc (Schiaffino & Reggiani 1996). These slow and fast muscle fibres (motor units) have different mechanical and metabolic properties. Type II is characterized by an ability to generate energy rapidly for quick, powerful actions and has a fast relaxation time. This relaxation time is determined primarily by the rate at which myosin splits adenosine triphosphate (ATP) (Frontera & Meredith 1989, McArdle et al. 1996, 330-331). The more type II fibres a subject has, the shorter time for force production. Both dynamic and concentric strength correlates with the percentage of type II fibres (Frontera & Meredith 1989).

The level of muscle tension is regulated by the number of active motor units and the frequency of single motor unit firing. Motor unit recruitment is a major determinant of force production. The number of muscle fibers in a motor unit depends on the muscle's functional movement. Intricate movement patterns require a small fiber-to-neuron ratio, whereas a single neuron may innervate several thousand muscle fibers for gross movements (Frontera & Meredith, 1989, McArdle et al. 1996, 354, Nienstedt et al. 1987, 78-79). Kraemer et al. (1996, 367) in their review call the concept of effecting activation of motor units "the size principle", which is based on the observed relationship between motor unit twitch force and recruitment threshold. Activation of motor units is a complex phenomenon influenced by neurophysiological mechanisms and psychological factors (Frontera & Meredith 1989). During the early stages of training especially, alterations in motor unit recruitment and firing pattern probably explain a large portion of the strength improvement with resistance training (McArdle et al. 1996, 355).

2.1.1 Different forms of muscle action

Neural stimulation of a muscle causes the contractile elements to attempt to shorten along the cells' longitudinal axis. When there is no change in muscle length during muscle activation, the action is called isometric or static. When movement of the skeleton takes place, the action is called dynamic. Dynamic (or isotonic) activity is further divided into eccentric and concentric action. Isometric action occurs when a muscle generates force and attempts to shorten but cannot overcome the external resistance. No external work is performed. Even though there is no noticeable lengthening or shortening of the muscle, and no joint movement, considerable muscle force can be generated (McArdle et al. 1996, 426-427, Nienstedt et al. 1987, 146).

2.1.2 Maximal strength

"The strength of a person can be defined as the maximum force which can be exerted against an immovable object (static or isometric strength), the heaviest weight which can be lifted or lowered (dynamic strength) or the maximal torque which can be developed against a pre-set rate-limited device (isokinetic strength)" (Frontera & Meredith 1989, Tittel & Wutscherk 1992, 180).

The strength of a muscle is determined mainly by its size, with a maximum contractile force between 2.5 kg and 3.5 kg/cm^2 of muscle cross-sectional area (Guyton 1986 132, 1009). Muscles operate by applying tension to their points of insertion into bones and the bones in turn form various types of lever systems (Guyton 1986, 133).

In the review of Holloway & Baechle (1990) they state that when expressed as the absolute amount of force exerted or weight lifted, the average woman has about two-thirds of the strength of the average man, which is well in line with results of Bäckman et al. (1995). Comparing strength on an absolute score, i.e. kilograms, men are usually considerably stronger than women for all muscle groups tested (McArdle et al. 1996, 422).
The peak of the maximal muscle strength is usually reached at the age of 20 for men and a few years earlier for women. On the average, the strength of a 65-year-old person is 75 to 80% of that attained between the ages 20 to 30. In leg and back muscles further decline to about 60% and to 70% in arm muscles from 30- to 80-year-old (Åstrand & Rodahl 1986, 342-343). As reported by Laforest et al. (1990), isokinetic strength of the elderly (about 65-year-old) in vastus lateralis ranged from 68% to 78% of that of the younger group (aged 25-30 years).

McArdle et al. (1996, 639) as well as Kraemer et al. (1996, 380) considered the reduction in muscle mass between 25 and 80 years of age to be 40 to 50%. The rate of the decline with age in the strength of the leg and trunk muscles is in both sexes, greater than in the strength of arm muscles. It appears that older, randomly selected groups are less physically active than younger age groups. This might be a reason why the aging person has a reduced number of motoneurons, and therefore a decline in muscle mass and strength (Åstrand & Rodahl 1986, 342-343, McArdle et al. 1996, 638).

Porter et al. (1995) found that women had greater eccentric/concentric muscle action ratios than men, but no interaction was found between age and sex. Women had a greater relative capability for eccentric torque, which could be explained by less eccentric neural drive in stronger subjects.

Nygård (1988, 50) reported in the longitudinal study of 3.5 years that the maximal isometric hand grip strength of the women with a high intensity of static occupational work was 86% of the strength of those with a low intensity of static occupational work. The mean grip strength of low intensity static occupational work group decreased 7% in the right hand during the follow-up period of 3.5 years (Nygård 1988, 53).

The results of Nygård (1988, 53, 71) also showed a great overall decrease in the muscle strength of middle-aged women during follow-up of 3,5 years. The decrease in trunk muscle flexion and extension strength was especially great. The calculated annual decrease was over 2,5% for women in trunk strength. The strength decreased about 10% for women aged 52. In grip strength the annual decrease among the women was about 2%.

According to above presented literature women are seen to be weaker than men but the decrease of strength related to aging seems to be similar among both sexes. The occupational status (including a very low or high musculoskeletal load) may influence to the decrease of muscle strength related to age. Benbem, Clasey & Massey (1990) indicated that although males are significantly stronger and can produce greater maximal rates of force than women, the results of force production are similar with respect to encouragement given. This suggests that if the primary concern is to produce a maximal strength, then instructions that require a hard and fast contraction are preferred by both men and women.

2.1.3 The force-velocity curve

Muscle has a capacity to adjust its active force to precisely match the load or resistance that it is experienced during shortening (the speed of the contractile system). The maximum speed of shortening can be seen to occur when the load is zero. Maximum force is produced when the muscle is stationary, i.e. neither shortening nor lengthening. The force-velocity relation is likely to reflect the kinetic properties of the cross-bridges. Various muscles in the body differ considerably with respect to their maximum speed of shortening. This is due to the structural heterogeneity of the contractile proteins among the muscles resulting in different kinetic properties of the myofilament system (Edman 1992, 96, Harries & Bassey 1990).

The isometric force-velocity curve is defined as the continuous record against time of the waxing of muscular force during an isometric contraction against an immovable resistance. When a maximal contraction is initiated, the generation of force is not immediately apparent. There occurs a period of a more or less gradual onset followed by a period of maximal increase which finally becomes asymptotic. This slow onset and final plateauing gives the curve a characteristic sigmoidal shape. The shape is similar among the skeletal and smooth muscles and muscle fibers of many different experimental animals (James et al. 1994). According to Going (1986, 183) 50% of maximum force is reached 5-10 times sooner in individual muscle groups than maximum force, and 75% of maximum force 3-6 times sooner.

In a review concerning velocity specificity of resistance training Behm & Sale (1993) concluded that resistance training at a specific speed will exhibit optimal gains at a similar testing speed with decreasing improvements as the testing speed deviates farther from the training speed. Hypertrophic adaptations may hinder high velocity torque, but velocity-specific contractile property adaptations have been demonstrated. Another mechanism underlying this effect may be an increase in the neural activation pattern of the muscle. Training programs including isometric, concentric and eccentric resistance training, and explosive jump training, have illustrated increases in EMG activity.

With the data of four different age groups of women, Stanley & Taylor (1993) indicated that in all subject groups, shorter muscle lengths were associated with maximal torque as the speed of muscle shortening increased. There does not exist a single muscle fiber length, for all angular velocities, for the development of peak torque. They also found in the isokinematic phase, that the further into the arc of motion peak torque occurs, the longer is the time to reach peak torque. The mean peak torque ratio of flexors and extensors, and also work and average power ratios, decreased with age inferring a differential loss of function in the aged. That is well in agreement with Going (1986, 183) who identified three general phases of force development over time in his study of young, middle-aged and elderly men.

Stanley & Taylor (1993), and Häkkinen & Häkkinen (1995) hypothesized that type II fiber loss and/or athropy may account for the decreased mean peak torque flexor:extensor ratio with age and that the shift in the angle at peak torque of the flexors seen in the 4th decade of women may be an early marker for this functional change. Porter et al. (1995) found, in young and older men and women, that the different decrease in eccentric and concentric strength might be explained by contractile velocity. Like Lexell et al. (1995) MacIntosh et al. (1993), Morris et al. (1983) and Stanley & Taylor (1992), Porter et al. supposed these alterations to be related in muscle fiber composition (see also Going 1986 182-183). Contrary to that, Laforest et al. (1990) found no difference in the relative decrease in peak torque with speed , suggesting minimal changes in hamstring muscle composition with age. Bäckman et al. (1995) noted in their epidemiological study that in some muscle groups there was no decline in strength due to aging.

Men produced higher knee extensor peak torque than women at different speeds in isokinetic dynamometer testing (Laforest et al. 1990). This was evident even when body stature was calculated and lean body mass was used to express torque output (by kilogram of lean body mass). Related to this difference of different speeds of force production, Bemben et al. (1990) found that the force-time curve of both sexes was affected similarly by the difference in instructions given to both sexes with respect to rate of hand grip squeeze.

There exists several on-line computer systems for recording and calculating selected force-time parameters. These time-samples analogue information are converted from analogue to digital representation. Parameters such as peak force, elapsed time to peak force, elapsed time to submaximum levels of force, the difference between adjacent force values, and the integration of all or selected parts of the curve are calculated from the discrete force and time values (Harries & Bassey 1990, James et al. 1994, MacIntosh et al. 1993).

2.2 Effects of strength training

A comparison of different protocols for muscle strengthening is complicated by the fact that it is difficult to compare the total load on the muscles involved. Individuals respond differently when exposed to a given program, and when entering such a program they may be in different states of muscular fitness. When training with weights in dynamic contractions, one talks about "nRM load", which is the number of repetitions of maximal load. The weight is chosen that can be lifted "n" times in proper style, but it is too heavy to lift "n + 1" times. With interspaced intervals, such a set is eventually repeated a number of times. One should keep in mind that all fiber types may be recruited in a maximal effort in a slow contraction against high resistance as well as in a fast contraction, resistance being less (Åstrand & Rodahl 1986, 429, 433).

Häkkinen (1990, 214) proposes to use 5 to 10 repetitions with a load of 50-70% of 1RM while aiming to enhance strength by speed power training. For the length of training periods of speed training Häkkinen (1990, 217) suggested 6-12 (+/- 2) weeks. For women, shorter periods might be more appropriate than for men.

In the study of current weight training males (training history <1 year) Wilson et al. (1993) found that after 5 weeks of training with 6-10 repetitions at maximal effort with different loads, according to the study group, isometric strength was enhanced best by weight training compared to plyometric strength training and control group.

Considering middle-aged women, the data at present is lacking precise results of long term effects of strength training. Thus, elderly men and women are widely studied and the results of those studies conclude strength can be increased and maintained with resistance training (Charette et al. 1991, Häkkinen & Häkkinen 1995, Lexell et al. 1995, Pyka et al. 1994, Sipilä & Suominen 1994, Sipilä et al. 1996). In the pilot study of Heislein et al. (1994) postmenopausal women aged 50-64 years were found to benefit from the specific exercise program developed for skeletal muscle strengthening. This study covered an 8 week period and had only 22 healthy, volunteer subjects and no respective controls. Heislein et al. (1994) concluded that a specific exercise program could be a feasible and effective approach to increasing strength safely in the postmenopausal female.

Contrasting to Heislein's et al. (1994) pilot study no significant differences were found between the progressive high-impact exercise group and the control group in the change of isometric maximum strength after training 3 times per week for 18 months. The isometric strength of trunk flexors and extensors, dominant elbow flexors and leg extensors were measured on premenopausal women aged 35-45 years (Heinonen et al. 1996b).

Muscle strength has been evaluated in relation to the muscle's cross-sectional area, but Lexell et al. (1995) and Pyka et al. (1994) have found no significant correlation between percentage strength improvements and percentage increase in the mean areas of muscle fibres. However, when the percentage increase in proportional area of type II fibres was regressed against the percentage increase in dynamic strength, it suggests that the weakest participants in both sexes gained the most benefit from heavy-resistance training.

Heinonen et al. (1996a) have also found muscle strength to increase in younger (23,8 +/- 5 years) women after high-intensity unilateral strength training of 12-months, five times a week. Pyka et al. (1994) found in their 70-year-old subjects that average muscle strength increased with strength training to levels that exceeded mean baseline values reported for young people entering exercise studies. Baseline muscle strength of those 70-year-olds (both men and women) was lower than that of younger men and women tested previously in the same laboratory.

Brown (1985, 13) revealed middle-age (40-49 years) women to gain strength with a similar rate to younger (17-26 years) women after 12 weeks of progressive strength training. Despite significant strength gains, there were no significant changes in circumference, skinfold measurements or weight in any of the subjects.

Trainability of middle-aged women seems to be good and dependent on the previous level of physical activity or baseline strength. The main outcome to improve is the trained muscle group or movement. The strength training or training to enhance power capabilities for 6 weeks to 18 months does not affect physical characteristics, like body mass, percent of body fat or limbs circumference in middle-aged subjects significantly (Brown 1895, Charette et al. 1991, Heinonen 1996, Heislein et al. 1994, Häkkinen & Häkkinen 1995, Lexell et al. 1995, Pyka et al. 1994). Contrary to this, Sipilä & Suominen (1995) both found strength and endurance trained elderly women decreased their body mass and body fat after 18 weeks of training.

Enhancing strength seems to be related to individual characteristics and former levels of physical activity. Although, based on recent literature, by choosing an appropriate mode of strength training women can as well as men can increase their current level of strength when you compare the mode of training used. Differences in response to strength training in general between men and women are most often observed as neural-related factors such as training background and the psychological interaction of the individual with the existing culture, biomechanical and hormonal factors (review of Holloway & Baechle 1990).

2.2.1 Plyometric training

Plyometrics, or explosive jump training is a special form of exercise training drill of speed power. A plyometric drill utilizes one's body mass and the force of gravity to provide the all-important rapid pre-stretch. Various standing jumps in place or rebound jumping (drop-jumping from a height) are structured to make use of the inherent stretch-recoil characteristics of skeletal muscle and its modulation via the stretch or myotatic reflex. In plyometric exercise overload is applied to skeletal muscle in a manner that rapidly stretches the muscle (eccentric or stretch phase) immediately prior to the concentric or shortening phase of action. The rapid lengthening phase in the stretch-shortening cycle probably facilitates subsequently a more powerful movement believed to enhance the speed-power benefits of this form of training (Häkkinen 1990, 214-5, McArdle et al. 1996, 436, Voight & Bradley 1992, 226).

All movement patterns in activities of daily living, and also athletics involve repeated stretch-shortening cycles. Prior to jumping, the loaded leg must stop the forward momentum and change it into an upward direction. As this happens, the muscle undergoes an eccentric lengthening contraction to decelerate the movement and prestretch the muscle. The neuromuscular system must react quickly to produce a concentric shortening contraction in order to produce an upward change in direction. Specific functional exercises that emphasize rapid change of direction can be used to prepare patients and athletics for a return to, or enhance, activity (Voight & Bradley 1992, 226). The aim of plyometric training is to decrease the amount of time required between the yielding eccentric muscle contraction and the initiation of the overcoming concentric contraction (Häkkinen 1990, 215, Voight & Bradley 1992, 226).

Specific plyometric drills for the lower body include a standing jump, multiple jumps and hops, repetitive jumping in one place, depth jumps or drop-jumping from a height of about 1 m (when considering athletes and less sedentary persons), single- and double-leg jumps and various modifications. The belief is that repetitions of these exercises will provide the proper neuromuscular training for enhancing the power performance of muscles used (McArdle et al. 1996, 436, Voight & Bradley 1992, 231-233).

Wilson et al. (1993) found that plyometric training of young, and previously trained adults for five weeks did not enhance the maximum isometric force. After that training the only improvement was seen in countermovements jumps. Thus, Wilson et al. (1993) concluded that the optimal training strategy to enhance dynamic athletic performance appeared to be a hybrid between traditional weight training and plyometric training.

In the study of premenopausal women aged 35-45 years Heinonen et al. (1996) found progressive high-impact trainees do significantly better than the controls after training both with, and without, extra weight.

In an epidemiological study, Kujala et al. (1994) found the vertical jumping height to be lower among women than men. The intensity, frequency, and duration of physical activity habits during leisure correlated with both aerobic power and explosive strength. The average vertical jumping test results of the physically active subjects were at least as good as that of their counterparts who were 10 years younger and physically inactive.

The plyometric training is traditionally used among athletes in order to accomplish more strength, and an ability to quickly produce high levels of strength. To see the improvements, the athletes have been tested by using a contact mat that utilized the same patterns of movement and muscle effort as training. Generalizing the effectiveness to non-athletes, such as average persons or subjects tested by other devices, the utilization of different patterns of movement or muscle effort is questionable, though worth studying.

2.3 Isometric strength testing

The maximum force that can be exerted by a muscle is influenced by several mechanical, electrochemical and biological factors. The anatomical characteristics of different joints restrict lengthening and shortening of muscles. The tension developed as a result of muscle activation varies with the angle of the joint. The effect of joint position on muscle strength is clearly related to the length-tension curve of skeletal muscle. Also internal muscle factors impact on force production: connective tissue layers, tendons and elasticity of the cross bridges in muscle constitute the elastic component (Frontera & Meredith 1989, Nienstedt et al. 1987, 144).

The isometric strength applied in a particular muscular effort may be measured with a calibrated dynamometer. Dependence of the force-velocity relationship i.e. the isometric force is maximal when the initial length of the muscle at the time of activation is approximately 20% above the equilibrium length. The force decreases linearly at lengths below this optimum and is zero when the muscle is maximally shortened (Åstrand & Rodahl 1986, 41, 388).

Nygård (1988, 64) found isometric strength tests for trunk muscles (flexors and extensors) reliable and no lack of motivation could be recognized. The finger flexors, thumb abductors, forearm extensors, foot plantar flexors and foot dorsiflexors were tested for maximal isometric force by Going (1986, 110). For maximal voluntary effort, static force-time curves were recorded from each muscle group and analyzed for curve parameters representing the amount of force produced by the muscles. The maximal rate of force increase, and the time elapsed from beginning of contraction to selected points on the curve representing different levels of force, were recorded and analyzed. With those measurements Going (1988, 54,113) found that performance had generally improved from the first to the second trial with no change from trial 2 to trial 3. After comparing all muscle groups and trials performance was found to improve over trials in maximum force. Also the increase in maximum rates of force was higher and the time to achieve maximum force was lower on the second and third trials of each test session than the first trial.

After reliable measurements obtained for knee extensor torque produced in maximal voluntary contractions, Kues et al. (1992) found that the majority of subjects reached their greatest peak torque values by the fifth or sixth contraction. By using an isokinematic dynamometer Weir et al. (1992) showed the maximal torque and integrated electromyogram high test-retest reliability for the forearm flexors and leg extensors. In this study, the dynamometer lever arm was placed 45 degrees below the horizontal plane for all leg extension tests.

In the cross-sectional and longitudinal study of Abernethy & Jürimäe (1996) the time taken for a significant increment in strength to be detected differed between isometric, isokinetic and isoinertial strength. There was a marked variation between strength indices in relation to changes in magnitude produced by 12 weeks of body-building type resistance activity.

According to Häkkinen & Häkkinen (1995) effects of heavy resistance strength training combined with explosive types of exercises to isometric force-velocity leads to improvements primarily in the earlier portions of the force-velocity curve. The above mentioned training enhances the ability to produce submaximal force faster than without or before specific training. The heavy resistance training combined with explosive types of exercise had also led to considerable shifts in the shape of the entire force-velocity curves, and to the significant increases in maximal rate force production. This can be seen in isometric muscle strength testing if force-velocity curve estimation is available.

2.4 Postmenopause and estrogen hormone

Usually at the age of 45 to 50 years the sexual cycles of a woman become irregular and ovulation fails to occur during many of the cycles. After a few months to a few years, the cycles cease altogether and the female sex hormones diminish rapidly to almost none. This period is called menopause and the cause of the menopause is "burning out" of the ovaries. During the sexual life of a woman about 450 of the primordial follicles grow into vesicular follicles and ovulate, while thousands of the ova degenerate. At the age about 45 years only a few primordial follicles still remain to be stimulated by the follicle-stimulating hormone and the luteinizing hormone (the anterior pituitary hormones, FSH and LH, respectively). The production of estrogen by the ovary decreases as the number of primordial follicles approaches zero. When estrogen production falls below a critical value, the estrogen can no longer inhibit the production of FSH and LH. Neither can the estrogen cause an ovulatory surge of FSH and LH to cause oscillatory cycles. Thereafter FSH (mainly) and LH are produced in large and continuous quantities (Guyton 1986, 979). The World Health Organization (WHO) has defined postmenopause to be the time period beginning from the menopause (stables cease of the ovulation) and which can be determined retrospectively (WHO Technical report series 1981, 670).

To overcome the menopause a woman must readjust her life from one that has been physiologically stimulated by estrogen and progesterone production to one devoid of these hormones. Often the loss of estrogen causes marked physiological changes in the function of the body, including "hot flashes," psychic sensations of dyspnea, irritability, fatigue, anxiety and occasionally various psychotic states. The symptoms are of sufficient magnitude in about 15% of women to warrant treatment. The estrogen deficiency also leads to diminished osteoplastic activity in the bones, to decreased bone matrix and to decreased deposition of bone calcium and phosphate. Among some women, this loss is severe and the resulting condition is osteoporosis (Guyton 1986, 974, 979). Hormone replacement therapy is currently used to prevent postmenopausal effects of estrogen deficiency like osteoporosis or arteriosclerosis (Osteoporoosin hoito ja ehkäisy 1992, 208, 215).

2.4.1 Postmenopausal female status in relation to strength training

The measurement that has been made in women has shown the basic physiological principles to be almost identical with men except for quantitative differences caused by differences in body size, body composition, and the presence or absence of the male sex hormone testosterone. The female sex hormone estrogen also accounts for some of the difference between female and male performances. Estrogen is known to increase the deposition of fat in the female, especially in certain tissues like the breasts and the hips. The average, sedentary female has about 26% body fat (Guyton 1986, 1008).

Moderate levels of exercise and resistance training elevate plasma levels of testosterone and estrogen in untrained women. Because the luteinizing hormone (LH) is normally released in a pulsatile manner, it is difficult to separate any specific exercise-related change from the normal pattern of pulsatile release. Several factors other than exercise may alter reproductive function of LH. Although, these altered levels of the follicle-stimulating hormone and LH are sometimes present among women with long history of heavy exercise (McArdle et al. 1996).

In the cross-sectional study of Taaffe et al. (1995) there was no difference between subjects according to estrogen replacement therapy status for lower-body muscle strength. This result was constant when muscle strength was normalized for body mass or lean body mass. Related to receiving estrogen replacement therapy, one year of estrogen use was not significantly correlated with lower-body muscle strength. These results indicate that although individuals receiving estrogen replacement therapy had enhanced bone mass compared to those not receiving the therapy, there was no effect of hormone replacement on lower-body muscle strength. In this study dynamic muscle strength of several large lower-body muscle groups was examined using isotonic resistance training equipment.

Brown et al. (1997) found a weight bearing exercise program to enhance strength of older postmenopausal women, although hormone replacement therapy did not augment the gains in muscle strength beyond those that occurred in response to exercise alone. The hormone replacement therapy had either no apparent effect on the increase in fat-free mass or gains in muscle strength.

Contradicting the findings of Brown et al. (1997) and Taaffe et al. (1995), Phillips et al. (1993) found estrogen replacement therapy to prevent menopausal decrease in specific muscle force. According to Phillips et al. (1993), it is possible that hormonal influences could alter the sensitivity of the muscle cross-bridges to metabolites affecting the muscle fatiguing or force production. They also suggested that some other factor affects the cross-bridge, reducing force development with aging. The estrogen in women is able to prevent the action of this unknown factor.

In the early cross-sectional study of Cauley et al. (1987) increasing age was associated with a reduction in grip strength among postmenopausal women aged 40-68 years. Women who reported current estrogen use, did not appear to lose strength with age and estrogen dose was positively correlated with grip strength. Those estrogen abstainers retained the decrease in grip strength with increasing age. Though, both height, weight and physical activity correlated positively with grip strength, it was independent of age, whereas the BMI was not. In summary, the primary determinants of grip strength in middle-aged women were height, age and physical activity, and postmenopausal women who used estrogen had significantly greater grip strength.

2.4.2 Anthropometry

Information concerning the association of muscle function and physique at middle-age and women is essential for a better understanding of changes in muscle function with age. It is generally accepted that larger persons on average, are capable of exerting more force than smaller persons. In an attempt to control for the influence of differences in size, comparisons of muscle strength between groups have been made with strength expressed relative to body mass (Sipilä & Suominen 1994, Sipilä et al. 1996). The validity of the strength to weight ratio, rests on the assumption that strength is proportional to body weight, a relationship that has not been established over a wide age range in either sex (Tittel & Wutscherk 1992).

Going (1986) did not find a correlation between lean body mass (LBM) and strength in his study of young, middle-aged and elderly men. In his conclusions, Going (1986), states that measures of limb circumference and muscle cross-sectional area are more highly correlated with force production than height and weight. Similarly, Nelson et al. (1994) found muscle mass to be directly related to strength.

3 STUDY AIMS

The objective of the present study was to test for the effective exercise mode with which to enhance the strength of postmenopausal healthy women. More specifically, the aims were:

1) To determine the effect of 26 weeks of plyometric training and estrogen replacement therapy on the isometric strength and the changes in the force-time curve of dominant side knee extension

2) To determine the effect of 26 weeks of progressive strength training and estrogen replacement therapy on the isometric strength and the changes in the force-time curve of hand grip and elbow flexion of the dominant side

4 MATERIAL AND METHODS

This study was a part of a larger research program on Exercise and Estrogen Replacement Therapy at the Department of Health Sciences at University of Jyväskylä during the Autumn 1996 and Spring 1997. The Exercise and Estrogen Replacement study was 52 weeks in duration and aimed primarily to show changes in the musculoskeletal system as well as develop methods for testing bone in human studies. I will reveal the effects of 26 weeks training, even when the exercises continued until the end of 52 weeks of progressive strength training and estrogen replacement therapy.

4.1 Subjects

A random sample of 1298 women aged 50-57 was drawn from the population register of the city of Jyväskylä. A questionnaire concerning health, menopausal status and medication was sent to them. In addition, through announcements in a local newspaper and in some of the biggest companies of the city of Jyväskylä 56 volunteered participants were contacted. Of this sample, 912 (70,3%) completed and returned the questionnaire. On the account of the questionnaire 794 women were rejected, because of current hormone replacement therapy (n = 288), no menopause or when menopause lasted over 5 years (n = 352), not willing to participate (n = 122), and when contraindications to exercising or hormone replacement therapy existed (n = 32). One hundred women who reported no severe diseases, functional impairments, and no former estrogen replacement therapy over two years were invited for clinical examination. The menopause among those invited for clinical examination was limited to last under 5 years and body mass index (BMI) under 32. After the clinical examination and FSH analyses (limit 30 IU/l) the sample was further reduced to 80 women. The subjects were randomly assigned to four subgroups (n = 20): estrogen replacement, exercise, estrogen replacement with exercise, and control group.

The subjects of the study groups were told to maintain their lifestyles as before they participated in this study i.e. if they were sedentary or non-estrogen users not to begin exercising or take any medication relating to estrogen or menopause. For those subjects in exercise or estrogen with exercise groups a progressive strength training program began two times a week for 52 (26) weeks.

The study was approved by the ethical committee of the Central Hospital of Central Finland. A written informed consent was obtained in advance from all the subjects.

4.2 Estrogen replacement

The hormone replacement was carried out under control of a physician. The women in the group of estrogen with exercise, and also in the group of estrogen were receiving Kliogest-pill of Novo Nordisk containing 2 mg estradiol and 1 mg noretisteron orally per day. The control group and the exercise group were taking placebo pills. The therapy was administered on a double-blind basis so that the researchers and the women of any group did not know what pills they were eating.

4.3 Exercise intervention

The exercise groups (a total of 40) participated in a 26-week progressive strength and explosive jump training program. (The explosive jump training will be regarded as plyometric training.) This training comprised of supervised training sessions of 1 h duration two times a week, and home training sessions of 20 to 30 min duration four times a week for 26 weeks. This 26 week period was interrupted twice for a two weeks aerobic dance period. Christmas, Easter and the First of May each caused one or two training sessions to be canceled due to a national holiday.

4.3.1 The circuit training routine

The supervisors of the 1 h training session were two trained physiotherapists, one of them present at all times. At the beginning of each supervised training session the supervisor led a warm-up period of about 10 min including aerobic dance steps and hops. At the end of the session, a few sets of trunk muscle strengthening exercises and stretching exercises to include the major muscle groups were performed. This order and realization of exercise was also held constant in aerobic dance sessions that concentrated on explosive jumps and muscle strengthening.

The training was performed at the gym in the city of Jyväskylä. The exercise machines used were those existing there and made by David (David International LTD, Finland) and Frapp (Frapp-kuntosalilaitteet, UK-Tekniikka OY, 82200 Hammaslahti, Finland). The resistance of machines was determined by kilograms in weight moving along different lever arms. The resistance of these machines provided concentric resistance although an eccentric phase was needed to control the movement. The dumbbells were used only for training of the biceps brachial.

The dynamic training was specifically directed at increasing the strength of muscle groups involved in the upper body. The exercises for upper body were chest fly, shoulder (military) press, biceps curl, seated row and latissimus pull down. Each training session included three of the above-mentioned upper body exercises chosen by the participant with 10 repetitions of each exercise. Each repetition lasted for 2-4 sec with no rest between repetitions. The intensity of the training was gradually increased so that during the orientation phase and during the three first weeks of training phase the load corresponded to 60% of the 1 RM measured with those exercise machines used for training. The 1 RM was defined as the heaviest load the subject could move in an acceptable way throughout the complete range of motion. After 16 weeks of training, the load was increased to correspond to 75% of 1 RM. At the end of 26 weeks the load corresponded to 80% of the 1 RM measured at the beginning.

A specific track was also constructed to provide the place for jumping and bounding activities at the gym. The explosive jump training included drop jumping, hopping, skipping and leaping. These drills were chosen to stimulate the explosive power production, enhance the strength of lower leg and stress the bones (see Table 1).

The complete supervised training session began with aerobic dance and hops in a warm-up for all participants together. The group was then divided into five subgroups, one for each "station of exercise". One subgroup began with 30 sec of rope jumping, the second with hopping, the third with drop jumping, the fourth with bounding, and the fifth with exercise machines. Under supervision participators began their circuit routine and after completing one "station" they rested for 30 sec while moving into another. During each circuit routine session, three laps of exercises were performed in order to complete all five stations three times. With a 10 min warm-up, 20-30 min strength circuit training period, and 15-20 min trunk muscle strengthening exercises and stretching of main muscle groups the whole training session lasted 1 h (see Table 1).

Table 1. The exercise circuit

EXERCISE	AMOUNT	MAIN FOCUS
A. Aerobic dance: step-sets	10 min.	overall warm-up
1. Rope jumping	30 sec	fast and low jump
2. Hopping	10 x/leg	concentrating on one leg at a time
3. Bounding	3 x 5 hurdles (of 10 to 18 cm)	jump height
4. Drop jumping	15 x from height of 10 to 20 cm	eccentric work
5. Resistance machines	10 x/machine	anaerobic muscle work
3 routines		
military press		60 to 80% of 1RM
biceps curl		
latissimus pull down		
seated row		
chest fly		
B. Trunk exercises	2 x 10 repetitions	activating trunk and providing
abdominal		motivation
back muscles		
C. Stretching	30 sec/ stretch	cool-down

The 1 hour duration of supervised resistive strength training session was organized 5 times per week and subjects participated twice per week. By having more training sessions available, subjects were provided with a possibility of choosing the sessions that might suit them best. This was in order to accomplish as high a compliance as possible.

During the training program all complaints about joint or muscle pain were considered and consultation to a physician was suggested if needed. All the participants got well used to progressive strength training and there were no complaints about pain. Most of the subjects of the exercise groups were enthusiastic and tried to do their personal best with exercises.

The peak ground reaction forces were tested at the baseline and at post-test among a subgroup sample of the exercise and the exercise with estrogen groups (Table 2). This was done in order to accomplish some knowledge about plyometric training and to the specific training regimen used.

Table 2. Peak ground reaction forces in body weights for all measured subjects (mean, SD)

	Baseline (n = 20)	26 weeks (n = 18)
Drop landings	4.3 (1.0)	5.2 (1.2)
Bounding	5.0 (1.1)	5.1 (1.0)
Skipping	3.9 (0.7)	3.6 (0.6)

4.3.2 The home exercise program

The home exercise program comprised primarily of jumping and hopping movements: 30 sec of skipping, 15 drop jumps from the height of 15 cm and 10 hops per leg, hands free. In addition, exercises to strengthen the abdominal and lower back regions were included as follows: 10 low-sit-ups and 20 diagonal leg-arm-lifts in a prone position. This circuit routine was meant to be performed three times. At the end of each home program stretching of major muscle groups was included. The home program was given to all participants in exercise groups in a written format. The home program was instructed to every participant and the adjustments of home environment were explained to each participant individually at the supervised training session. If some of the exercise groups could not join the supervised exercise for some reason, she was told to do four routines of home training program instead.

4.3.3 The training diaries

The supervised resistive training was monitored by training diaries. Subjects reported the load used in the exercise machines, repetitions done per session per machine, routines of training, and the amount of jumping, to the training diaries at end of each training session. With those diaries the loads were kept on appropriate level and the compliance on exercises held on a regular basis (Appendix 1). Regardless of study group, i.e. estrogen, estrogen with exercise, exercise or control, each subject was given a training diary to take home. In their home diaries they wrote exercises they performed at leisure time, on the way work or other physically demanding activities they considered to be exercise for themselves in order to collect the data concerning exercises outside this study. The length of training (in minutes), the exercise and kilometers covered per day were entered in to the home training diaries also (see Appendix 2).

All the subjects of the exercise groups were told to maintain their previous level of physical activity. They were asked not to participate any new vigorous activity on a regular basis during this 26 week period. The normal variation of physical activity related to season, work and state of mind was allowed. In order to identify possible changes with physical activity due to the study, their current level was monitored by the initial questionnaire.

4.4 Measurements

4.4.1 Anthropometry

Body height, body mass and lean body mass (LBM), together with body fat measured using bioelectrical impedance with the manufacturer's equations (Spectrum II, RJL Systems, Detroit, MI, USA), were determined. Trained personnel performed the bioelectrical impedance measurements at 8.30-10.30 h. The machine was checked daily with a standard resistor. Before the measurements the subjects had fasted 3-4 h and not exercised for at least 12 h. In our laboratory, the coefficient of variation between two consecutive bioelectrical impedance measurements has been in the order of 2-3%.

Body height and body mass were determined using a standardized measurement system and a trained person to collect the data.

One of the examiners of isometric strength measured the lower leg, lever arm, that is the distance between the lateral joint line of the knee and mid-line of a cuff around the ankle, with a flexible steel tape. The same examiner also measured the arm lever of the forearm, i.e. the distance between the lateral joint line of elbow and mid-line of a cuff around the wrist, with a flexible steel tape. Both the length of the forearm and the length of the lower leg were entered in to the measurement record as centimeters. The results were used to calculate the specific tension of the respective muscle groups. The measurement was conducted after the subject was properly adjusted to the chair.

4.4.2 Isometric muscle strength

Maximal isometric strength was determined on the dominant side. The forces of hand grip, elbow flexion and knee extension were measured in a sitting position on a custom-made dynamometer chair (Sipilä et al. 1996). During the tests subjects sat in a comfortable position and the length of back support, elbow support and grip length were determined on the scale of the chair. The height of back support and elbow support were also determined on the scale of the chair. These measurements were done by two trained examiners in order to provide reliability and reproducibility of measurements over time.

Isometric forces were recorded as a force-time curve on a computer using a Codas (Data Instruments, Inc. Akron, OH, USA) data acquisition program. By that program the force-time curve was seen simultaneously as the force was produced, on the scale on the screen. To analyze the force production the program calculated forces for each 100 ms measured and the maximal force achieved during the 500 ms recorded. From the screen scale the curve with the highest force was selected if the force was produced within first 150 ms and then maintained to the end of 500 ms. If that criterion was not met during three trials of maximal force production, the subjects were encouraged to produce the force in more proper way. In order to give subjects immediate feedback of their performance an amplifier was used beyond the computer to give an accurate force produced in kilograms. The availability of an estimation of force-time production gives the justification for using isometric strength testing even though it is not directly stressed on the training program of this study.

4.4.3 The test protocol of isometric strength testing

At the beginning of the test situation the subject was placed on the chair and her position was adjusted, after which one of the examiners explained her the standardized way that was needed to produce the maximal isometric force in each muscle group separately. Before each test pattern the subject was asked to practice three times: once as fast as possible but only with 25 % of her supposed maximal force, once as fast as possible with 50% of her supposed force and hold that force for 4-5 sec, and once as fast and as hard as possible. After these rehearsals the subject was told to rest for one minute before the actual tests. This protocol was held constant in pre-tests and post-tests. The protocol had been tested before in this same laboratory by Sipilä et al. (1996), the coefficient of variation between two consecutive measurements was 6.3%.

The learning effect, known to affect strength testing, was controlled by using those rehearsals before actual testing. The instruction and three practice efforts seen on the screen showed the testers that subjects were performing as required. During rehearsals, subjects were told how they performed according to the force-time curve on the screen and were instructed more, if needed.

During that one minute before actual tests the subject was instructed about the test protocol and fast force production was emphasized. Each subject was instructed "ready" to prepare her and achieve her full attention, and "Now!" to start the force production as fast as possible with full strength from the very beginning. During the 2-5 sec holding phase each subject was encouraged to give her best and then release the maximal effort when instructed. Between each test was 60 sec of rest. At least 3 tests were performed in order to achieve the subject's best and maximum force. If the result kept rising over 1 kg after the third test, the test was continued until the strength values ceased rising or began to decrease.

For *the hand grip* test the subject sat in the test chair and was instructed to place her dominant hand into a cuff so that the lower arm was in a horizontal position. The upper arm was in a vertical position and the subject was instructed to hold her arm still, but relaxed. The hand grasped a special hand grip apparatus of the test chair. The wrist was placed in a neutral position with fingers flexed around the special hand grip apparatus. No fixations were used. The hand grip is test provides a stable force parameter, i.e. hand grip strength is hardly altered by exercising.

The *elbow flexion* test was the same set-up as the hand grip the only exception being was a strap placed above her wrist (distal end of radius and ulnae) to provide the fixation for force production and the special hand grip apparatus was removed. The non-dominant hand was placed on the legs so it would not be used to stabilize the position. The elbow flexion was tested for upper extremity force alterations after 26 weeks of dynamic strength training. The fixations used and the isometric testing regimen provides repeatable measurements that measure the strength of elbow flexors.

The knee extension test was carried out by placing the dominant leg on the device with a cuff over the ankle just above the lateral malleolus. With the lever arm of the device being supported by the examiner, the knee was placed at 120° of extension, as measured with a goniometer. The sleeve of the unit was tightened into place at this angle to support the knee in a fixed position during testing. A strap was tightened up around the pelvis and the back support of the test chair in order to stabilize the lower body.

The best performance of three trials was accepted as the result. To obtain maximal isometric muscle torque, the highest recording was multiplied by cos. 30° x lever arm. The force results were further divided by body weight to obtain a measurement of relative force and torque.

All measurements were performed and recorded by two examiners. Pretesting and post-testing with the isometric strength testing was performed by the same two examiners. The protocol was held constant for baseline and post-testing and the encouragement and feedback was given in a standardized way to each participant regardless of which group they were randomly chosen. Before testing, subjects were asked not participate any vigorous exercise or activity for two days. Subsequent to testing they were asked if they were on medication and what for, and did they have muscle- or joint-pain.

4.5 Statistical analysis

The statistical analyses were done by SPSS for Windows release 6.1 system (SPSS Inc., USA). Standard statistical methods were used to calculate mean and standard deviation (SD). One-way ANOVA was used for the difference between the study groups at the baseline. The differences of physical characteristics, physical activity and force results between the study groups at baseline and post-tests were compared by using repeated measures of ANOVA. If the significance of the interaction of group by time was $p < 0.10$, the training effect was localized utilizing simple contrasts. The level of statistical significance chosen for the contrasts was $P < 0.05$.

5 RESULTS

5.1 The level of exercising and the compliance with the study

There were 7 drop-outs in the exercise group and 9 in the exercise with estrogen group during the 26 weeks of training. Three subjects were not willing (due the lack of time) to participate in the supervised training sessions from the beginning. Another three of the subjects suffered from prolonged flu or acute respiratory infection. Two of the subjects dropped out due to the self reported health concerns. Four of the subjects felt side effects or did not find the estrogen replacement therapy useful and quit using them. These four subjects were rejected from the statistical analysis even though two of them completed the 26 weeks of training and post-tests. Lack of time was the reason for two of the objects to drop out of the study. Furthermore, three subjects were left out of the analysis due to too a poor participation rate. During the post-tests the hand grip and the elbow flexion of one subject was not tested due to a broken dominant wrist. Two of the subjects who were currently participating in the supervised exercises could not schedule the post-tests due to their work (n = 26).

Seventeen subjects both of the control group and the estrogen group completed the study. The reasons for the absence in the study of the six subjects for control and estrogen group were lack of interest and time, side-effects of estrogen replacement therapy (n = 3), and examination requirements. Rheumatoid arthritis was the reason one subject could not be tested for hand grip.

The baseline levels of physical activity were similar in each of the study groups. One third of the subjects in each group participated in light outdoor activities or walking on 1-2 days per week. Less than 30% of subjects in each group participated in activities that made them sweat at least once or twice per week or more. The remaining 30% of subjects did light activities or walking (approximately 15% of subjects) several times per week, or did not exercise (over 10% of subjects). These estimations of activity level were collected via the study entering questionnaires and the above mentioned levels were given in the questionnaire (see Table 3, page 25).

For the baseline measurements (body mass, body fat, body height, level of physical activity or intensity of physical activity) there was no difference between women who completed the study to those who did not.

5.1.1 The home training diaries

When entering the study, each subject was given a home training diary. Via these diaries 8 weeks of home training was collected before the 26 weeks of intervention began. The training of the study groups is shown in Table 3. Comparing the given figures, there were no significant differences between the study groups.

The most popular mode of exercise among 60 of the 80 women (75%) selected for the study groups was walking (most of subjects in each group went walking on a regular basis), of the study groups. The second most popular mode of exercising was cycling (n = 34, 42.5%), then home gymnastics (n = 20, 25%), cross-country skiing (n = 18, 22.5%) and swimming (n=16, 20%). The activities related to house work were often (n = 28, 35%) classified as exercising that requires effort similar to physical exercise. The other modes of exercising in each study group in order of popularity were water gymnastics, instructed exercises, weight training, dancing, aerobics, running, rowing, down-hill skiing, taichi and volleyball. Between study groups, there were no differences in modes of physical activity, i.e. above mentioned modes were equally participated.

There was no significant changes in levels of self assessed physical activities between the data collected in the initial questionnaire and the questionnaire after 26 weeks. Within study groups, differences in self-classified home exercises were minor. The changes seen were mostly between subclasses (i.e. increasing the level of participating of physical activity from 1 to 2 times per week to several times per week), not from the lowest level (not exercising) to the highest level (daily heavy exercising) or vice versa.

According to home exercise diaries the mean frequency of exercising per week during the 26 weeks is seen in Table 3, while the attendance of exercise groups to supervised training sessions was left out of calculations. The minor differences seen between study groups had no statistical significance. Time significantly affected the level of exercising: all study groups seemed to have increased their level of physical activity according to home training diaries during the 26 weeks of intervention. Both the frequency per week and the time per week were highly increased.

Table 3. The self-classified exercising level and the training frequency and duration before and during the intervention of 26 weeks (mean, SD)

	Exercise (n = 13)		Exercise with estrogen(n = 11)		Estrogen (n = 17)		Control (n = 17)				
Self-classified exercising	BL	26wk	BL	26wk	Bl	26wk	Bl	26wk			
Not exercised (n)	1	1	0	0	2	2	1	0			
Light 1-2/wk (n)	6	1	3	1	6	6	4	3			
Light >3/wk (n)	3	2	1	3	2	2	0	3			
Sweat 1-2/wk (n)	3	4	4	3	2	3	8	5			
Sweat >3/wk (n)	0	5	3	4	5	3	3	3			
									ANOVA significance (p)		
	BL	26wk	BL	26wk	BL	26wk	BL	26wk	Time	Group	IA
h/wk	2.6	4.3	3.2	5.8	2.6	4.7	3.2	3.8	<0.001	0.359	0.183
(SD)	(1.5)	(1.7)	(2.0)	(2.1)	(2.2)	(2.3)	(2.1)	(2.2)			
times/wk	2.9	4.9	3.7	5.6	2.4	3.9	3.4	4,3	<0.001	0.130	0.202
(SD)	(1.7)	(1,7)	(2.3)	(1.3)	(1.6)	(1.7)	(1.8)	(1.7)			

(BL, baseline)

The study groups included subjects who did not take any physical activities during a week for the reasons of lack of interest, sickness, vacation, injury or weather. The absence of exercising was not regular or longer than 4 weeks for any of the subjects who had previously exercised. However, three of the subjects without previous exercise began exercise during the 26 weeks of intervention. These subjects were in the estrogen group, in the estrogen with exercise group and in the control group. One (1) subject in the estrogen group reported not exercising during the 26 weeks of intervention, even though she had previously been involved with light exercising 1-2 times per week.

According to the home training diaries the subjects in the exercise with estrogen group seemed to exercise slightly more and more regularly at their leisure time than did the subjects in other groups. The exercise modes used during the intervention remained the same among all the study groups as they were before the intervention.

While comparing the quality of reporting accuracy in the home training diaries, a variety of levels of reporting was seen. Most of the subjects returned the diaries as required, i.e. after 26 weeks of intervention. There was only one (1) diary missing and one (1) was partly completed. The level of participation in physical activity was collated as hours (minutes) spend, and kilometers covered. Also the mode of activity was reported on a daily basis. Some of the subjects reported only kilometers covered or hours spent, so the time of the activity was chosen for comparison.

The exercise and exercise with estrogen groups were instructed to report their participation in the supervised training sessions, and the home exercise program, to the home training diaries. The frequency of the home exercise program was on the average once per week in exercise group (n = 8). On the average, in the exercise with estrogen group the home exercise program was done almost twice a week (n = 9). However, several (n = 5) subjects reported having completed the home exercise program as required, 3 times per week.

5.1.2 The supervised circuit training

The compliance of the study was fair among the 24 subjects in the training groups that were available for post-tests. The participation rate in the training program was on average 71%. During the 26 weeks of intervention, the subjects of the training group participated in supervised training sessions on average once per week. A clear difference between subjects was seen: some of them participated in almost 95% of supervised sessions. Contrasting these, were 7 women participating in supervised training sessions more or less occasionally. The reasons for several absences from supervised training sessions were due to sickness, injury (not related to the study), a trip abroad, or changes in shifts of work. The subjects who were forced to skip a supervised training session reported doing four sets of the home exercise program instead, as instructed.

By further dividing the rate of attendance of supervised training sessions, the mean rates of exercises done per week remained under once per week. The exercises most often done were chest fly and seated rowing (0.7-0.9 times/week, each). The biceps curl was the least done exercise, 0.6 times per week. There were no differences between the two exercise groups, exercise and exercise with estrogen. While considering the given rates of exercises done, one must keep in mind the type of training used. The circuit training system provided the opportunity to choose the upper body exercise for the subjects. Three laps of the circuit per session provided the possibility of only three upper body exercise modes to be done per session.

The first aerobic period for two weeks was in February and the other was in April. Only 10 of the 25 women of exercise groups participated in aerobic sessions for one hour. The aerobic sessions were held three times per week and the subjects chose two sessions per week that suit them best. The average participation was once per week.

The level of exercising in circuit training sessions was estimated by measuring the one repetition maximum for each upper body training machine used. At the beginning, the resistance of the training machines was set to 60% of 1RM, and at the end of 26 weeks of intervention the level was 80% of 1RM. The levels of 1RM were measured at the beginning of the 26 weeks of intervention as well as at the end of that time period. The means of 1RM measured at each of training machines were increased during 26 weeks of training. Both the exercise and the exercise with estrogen groups increased their 1RM levels. The exercise group increased their 1RM level by an average 1% in the military press, 8% in seated rowing, 9% in the biceps curl, 10% in the lateral pull down and 16% in the chest fly. The average increase in the exercise with estrogen group was 9% in the military press, 12% in seated rowing, 12% in the biceps curl, 21% in the lateral pull down and 30% in the chest fly. The correlation of 1RM results with attendance to supervised training sessions was statistically significant only in the chest fly (0.66, $p = 0.003$).

5.2 Anthropometry

At the baseline, no measured anthropometric characteristic differed significantly between study groups. Over time, the changes in body height, body mass or in lean body mass were minor, and except for height, not statistically significant (Table 4). However, there was a significant interaction of group by time in body fat, the change in the exercise with estrogen group being greater than that in the controls.

Table 4 Physical characteristics in postmenopausal women before and after 26 weeks of resistance training (mean, SD)

	aExercise (n = 13)		bEstrogen with exercise (n = 11)		cEstrogen (n = 17)		dControls (n=17)		MANOVA significance (p)			
Variable	BL	26wk	BL	26wk	BL	26wk	BL	26wk	Time	Group	IA	Contrasts
Body height	164.0	163.8	162.0	161.9	159.8	159.3	162.6	162.3	<0.001	0.249	0.161	
cm	(4.2)	(4.3)	(6.4)	(6.4)	(6.8)	(6.6)	(6.0)	(5.9)				
Body mass	70.2	70.7	66.0	65.7	69.5	69.3	68.1	68.0	0.943	0.699	0.862	
kg	(11.7)	(12.2)	(9.1)	(9.0)	(10.1)	(9.2)	(11.2)	(10.0)				
LBM	46.6	46.8	46.4	47.0	45.6	46.1	47.4	46.9	0.245	0.866	0.143	
kg	(4.4)	(3.8)	(4.5)	(4.2)	(4.2)	(4.2)	(4.9)	(5.1)				
Body fat	33.8	33.5	29.1	27.8	33.9	33.3	29.6	30.4	0.165	0.090	0.073	a-b 0.249
%	(6.4)	(7.8)	(6.5)	(6.0)	(6.1)	(5.2)	(5.7)	(4.8)				a-c 0.650
												a-d 0.179
												c-d 0.056
												b-c 0.432
												b-d 0.013

(BL, baseline)

5.3 Knee extensor strength

There were no differences in baseline levels of the study groups in knee extension force, knee extension torque, or knee extension torque related to body mass. The effects of exercise and estrogen on knee extension force and torque are seen in Table 5.

Table 5 Effects of plyometric training on knee extension (KE) force and torque expressed in absolute and relative terms in postmenopausal women (mean, SD)

	aExercise (n = 13)		bExercise with estrogen (n = 11)		cEstrogen (n = 17)		dControl (n = 17)		MANOVA significance (*p*)			
Variable	BL	26 wk	BL	26wk	BL	26 wk	BL	26wk	Time	Group	IA	contrast
KE force	457	491	443	483	444	491	452	443	0.001	0.814	0.046	a-b 0.830
N	(80)	(60)	(102)	(94)	(81)	(73)	(94)	(82)				a-c 0.576
												a-d 0.054
												c-d 0.009
												b-c 0.760
												b-d 0.040
KE torque	132	139	125	132	126	136	133	126	0.053	0.853	0.016	a -b 0.849
Nm	(20)	(17)	(28)	(25)	(28)	(22)	(28)	(24)				a-c 0.651
												a-d 0.018
												c-d 0.003
												b-c 0.528
												b-d 0.038
KE torque/	1.94	2.04	1.98	2.08	1.80	1.97	1.96	1.86	0.028	0.733	0.011	a-b 0.967
body mass	(0.47)	(0.47)	(0.48)	(0.43)	(0.31)	(0.30)	(0.33)	(0.34)				a-c 0.455
Nm kg^{-1}												a-d 0.023
												c-d 0.002
												b-c 0.504
												b-d 0.027

(BL, Baseline)

There was a significant interaction of group by time in the knee extension force, torque and torque related to body mass. The changes in knee extension force and torque were significantly greater in all three experimental groups when compared to the controls. The individual percentage changes in maximal knee extension torque are seen in Figure 1.

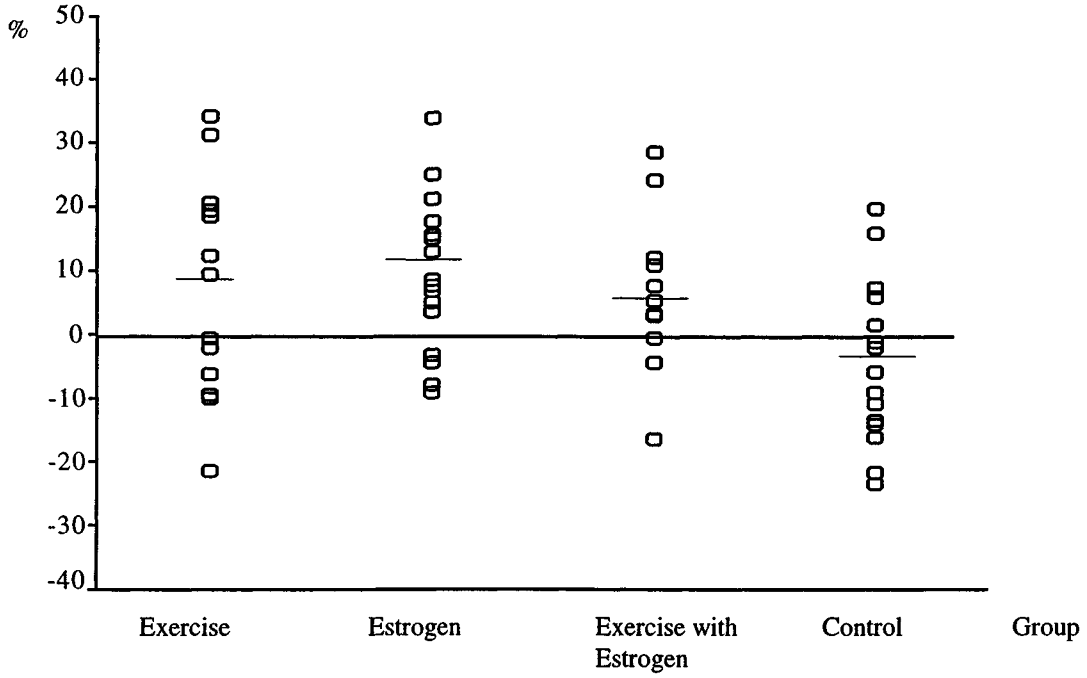

Figure 1. Individual percentage changes of isometric knee extension torque during 26 weeks of exercise and estrogen intervention (— indicates means)

The force-time curves of knee extension showed no statistically significant changes during the first 100 ms of force production (Figures 2a - 2d), but the knee extension force levels during 200-500 ms increased in all study groups ($p < 0.001$), except the control group during 400-500 ms.

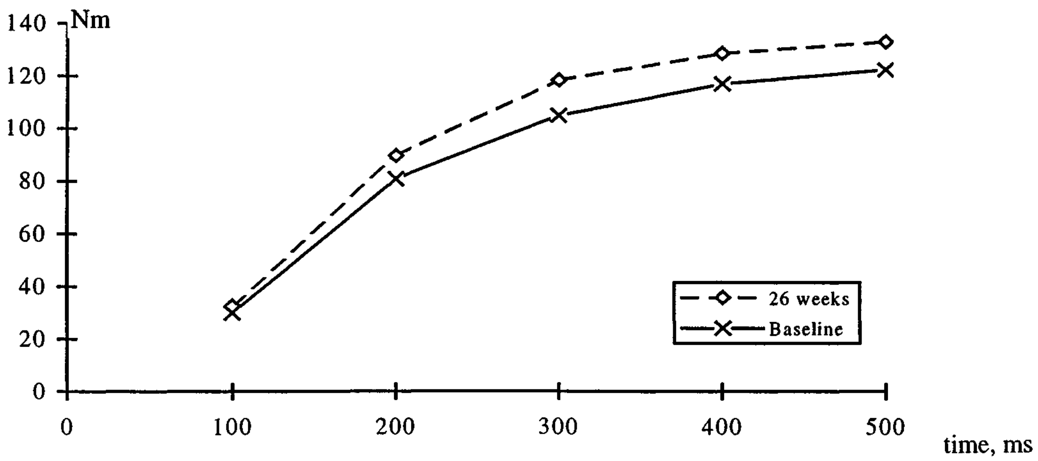

Figure 2a Averaged force-time curves for isometric knee extension torque for the exercise group

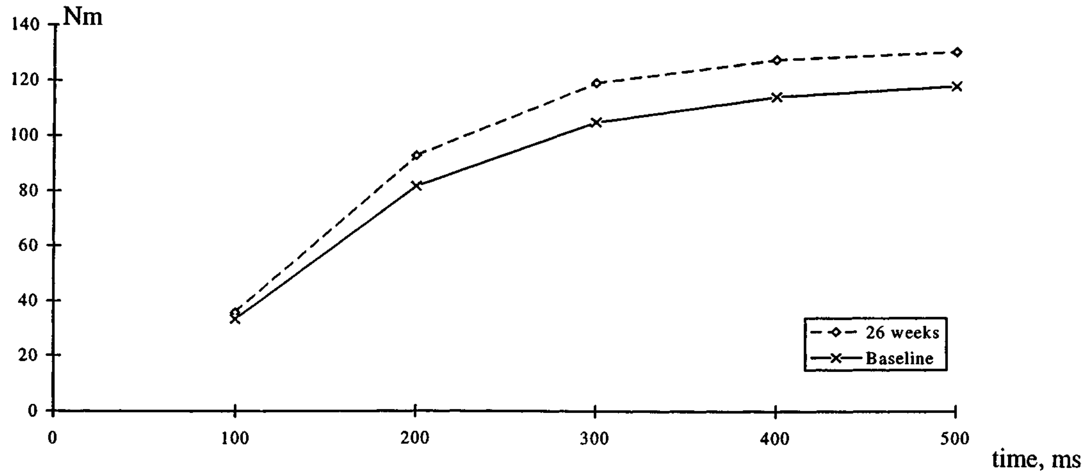

Figure 2b Averaged force-time curves for knee extension torque for the estrogen group

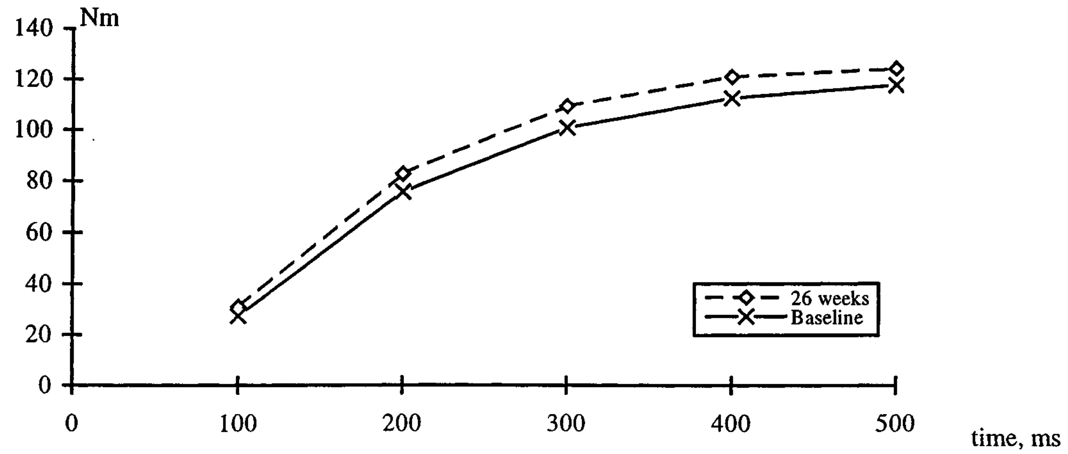

Figure 2c Averaged force-time curves for isometric knee extension torque for the exercise with estrogen group

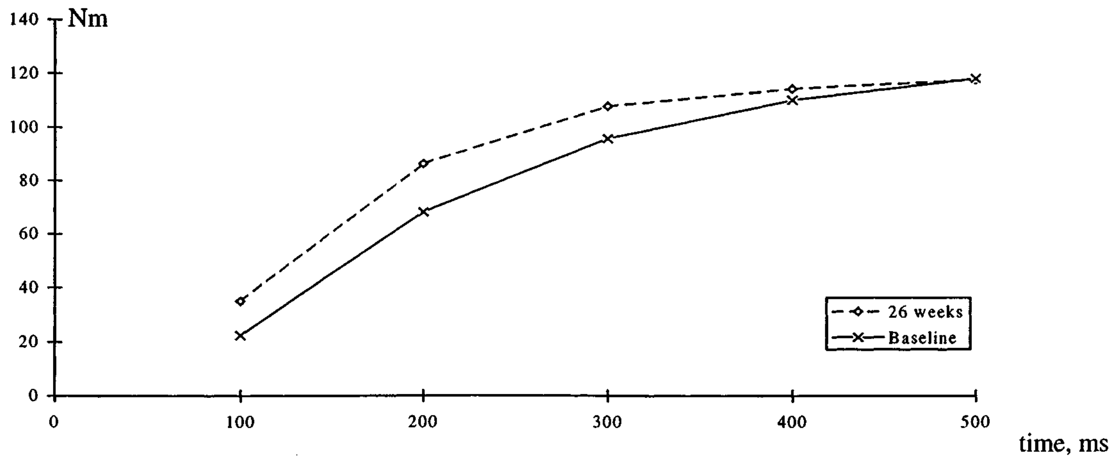

Figure 2d Averaged force-time curves for isometric knee extension torque for the control group

5.4 Hand grip and elbow flexion strength

Table 6 Effects of strength training on hand grip force (HG), elbow flexion (EF) force, and torque expressed in absolute and relative terms in postmenopausal women (mean, SD)

	aExercise (n = 13)		bExercise with estrogen (n = 11)		cEstrogen (n = 17)		dControl (n = 17)		MANOVA significance (*p*)			
Variable	BL	26 wk	BL	26wk	BL	26 wk	BL	26wk	Time	Group	IA	contrasts
HG force	351	352	354	372	305	319	335	340	0.107	0.313	0.891	
N	(90)	(104)	(87)	(84)	(72)	(68)	(58)	(79)				
EF force	259	281	294	290	273	280	283	261	0.924	0.708	0.042	a-b 0.126
N	(52)	(57)	(52)	(39)	(52)	(46)	(63)	(69)				a-c 0.348
												a-d 0.007
												b-c 0.454
												b-d 0.292
												c-d 0.045
EF torque	59	64	66	65	61	64	61	60	0.451	0.818	0.058	a-b 0.133
Nm	(13)	(13)	(14)	(9)	(13)	(11)	(18)	(16)				a-c 0.459
												a-d 0.012
												b-c 0.363
												b-d 0.375
												c-d 0.046
EF torque/	0.86	0.95	1.04	1.03	0.88	0.93	0.94	0.88	0.410	0.265	0.069	a-b 0.165
body mass												a-c 0.499
Nm kg^{-1}	(0.23)	(0.24)	(0.22)	(0.15)	(0.18)	(0.17)	(0.20)	(0.22)				a-d 0.015
												b-c 0.395
												b-d 0.354
												c-d 0.048

(BL, baseline)

The results of elbow flexion force and torque, and hand grip force are shown in Table 6. There were no statistically significant differences between study groups at the baseline. The hand grip force showed no change over time or between groups. The interaction of time and group was significant in elbow flexion force, in elbow flexion torque, and elbow flexion torque related to body mass. In elbow flexion force, elbow flexion torque, and elbow flexion torque to body mass, the change in the exercise and estrogen groups differed with statistical significance from that of the control group. The individual percentage changes of hand grip and elbow flexion force are shown in Figures 3 and 4.

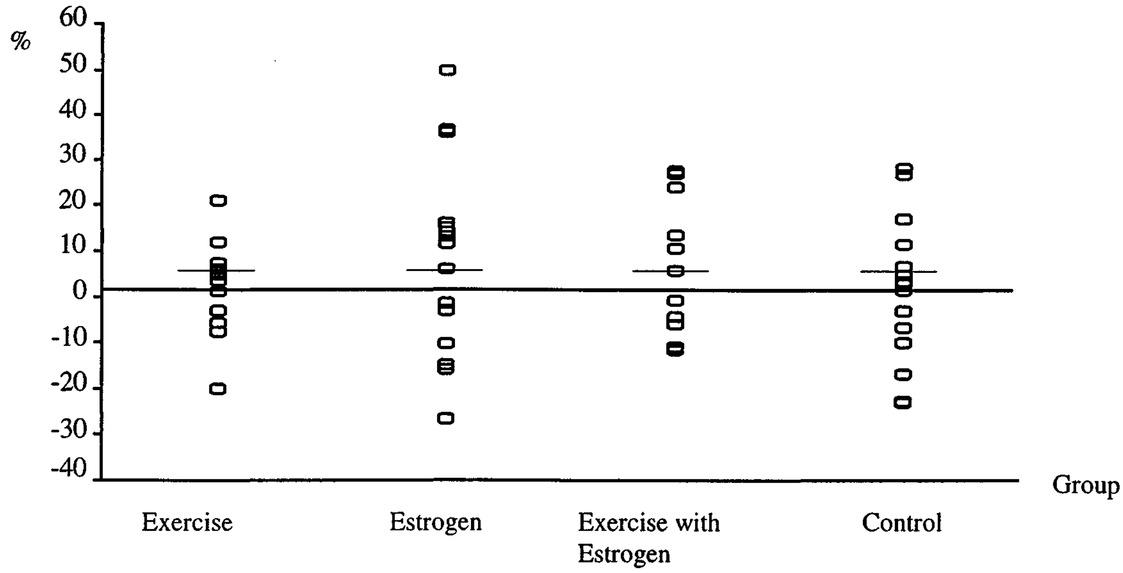

Figure 3 Individual percentage changes of maximal isometric hand grip force after 26 weeks of exercise and estrogen intervention (— indicates means)

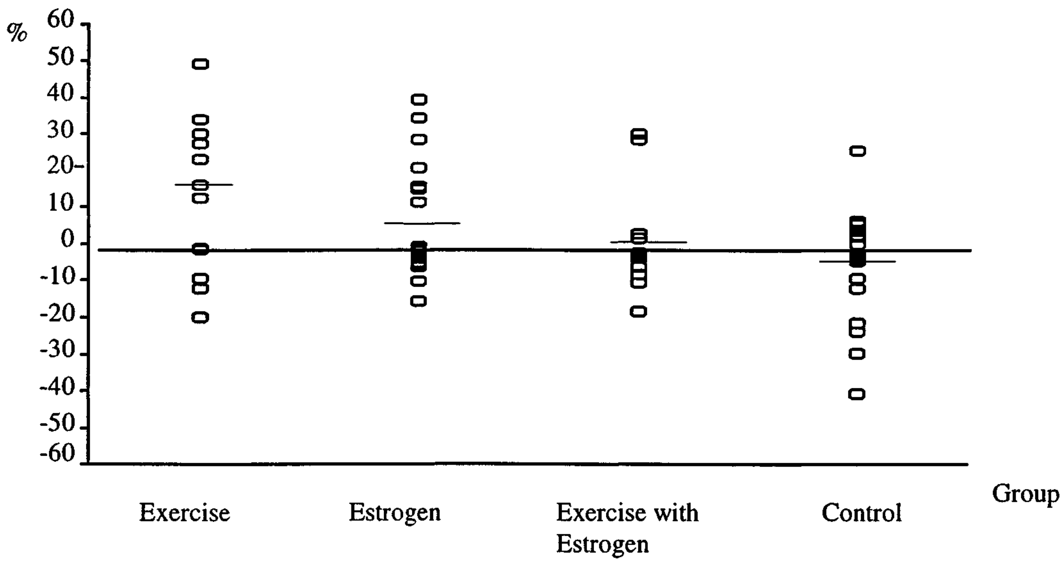

Figure 4 Individual percentage changes of maximal isometric elbow flexion torque after 26 weeks of exercise and estrogen intervention (— indicates means)

The force-time curve of hand grip force showed a significant overall force production increase over time in early parts of the curve i.e. during the first 100 ms to 200 ms, $p = 0.005$. Group effect or group interaction with time was not significant. At 300 ms the overall force production was increased significantly, $p = 0.03$. From 400 ms to 500 ms the overall force production was not changed, the statistical significance (p) was over 0.05.

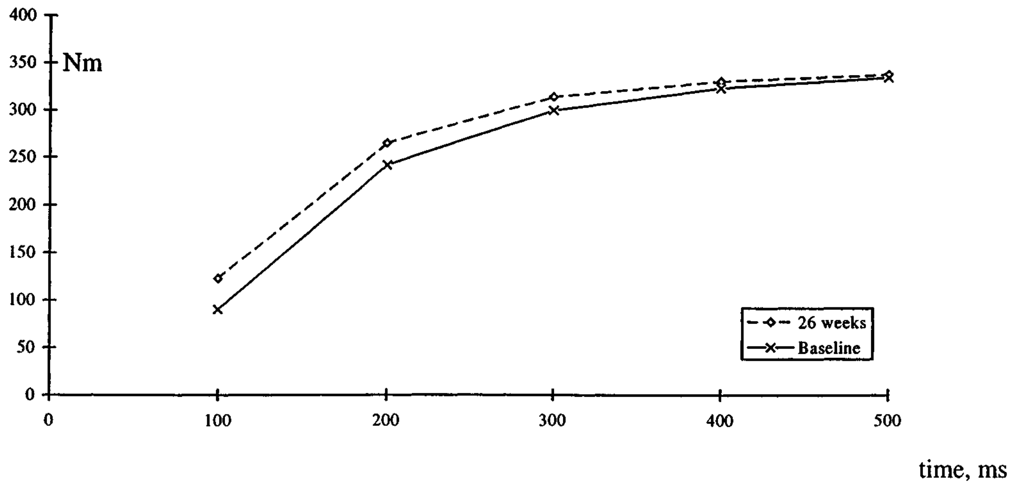

Figure 5a Averaged force-time curves for isometric hand grip force for the exercise group

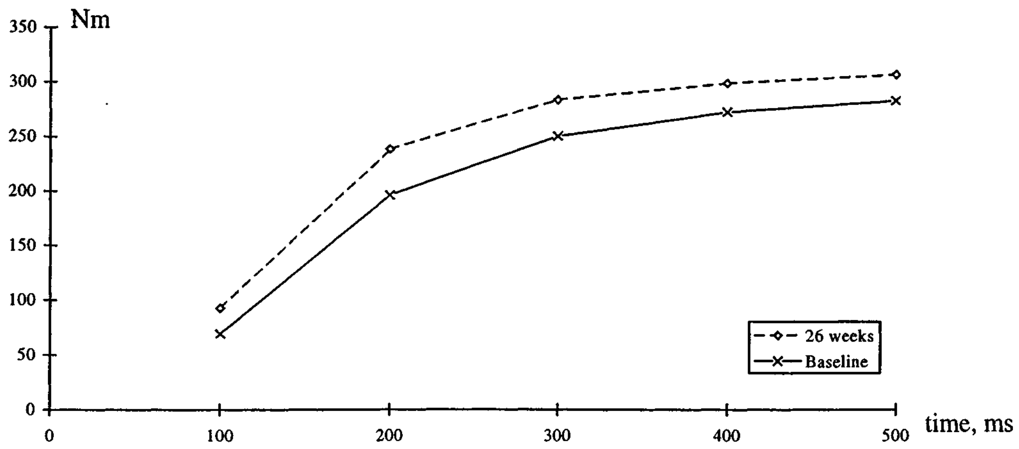

Figure 5b Averaged force-time curves for isometric hand grip force for the estrogen group

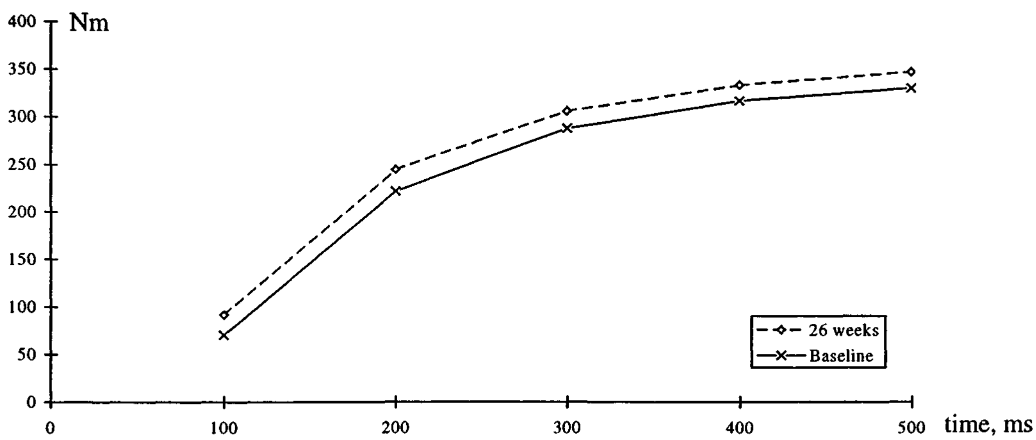

Figure 5c Averaged force-time curves for isometric hand grip force for the exercise with estrogen group

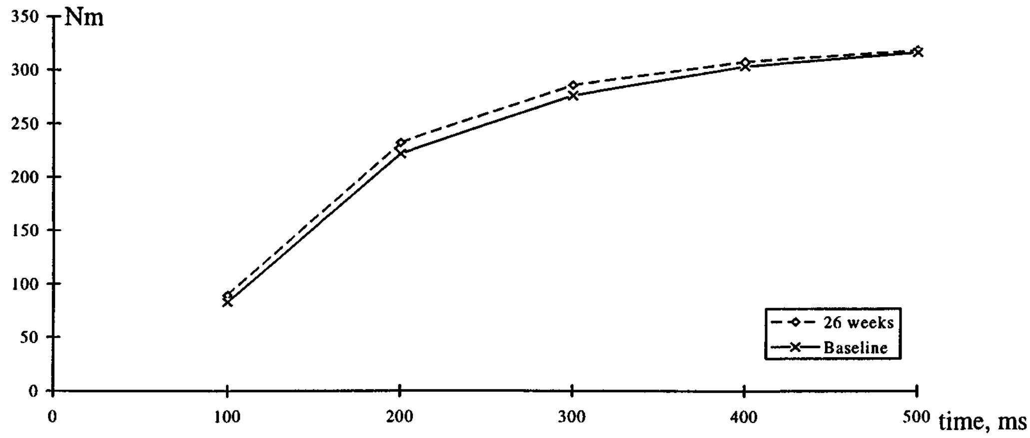

Figure 5d Averaged force-time curves for isometric hand grip force for the control group

The force production curve for elbow flexion changed significantly in the three intervention groups compared to control group. There was a significant interaction of group by time at 300-400 ms ($p < 0.02$) and at 400-500 ms ($p = 0.003$), the change in the exercise group being greater than in the control group. At the early parts of force production there was no change seen.

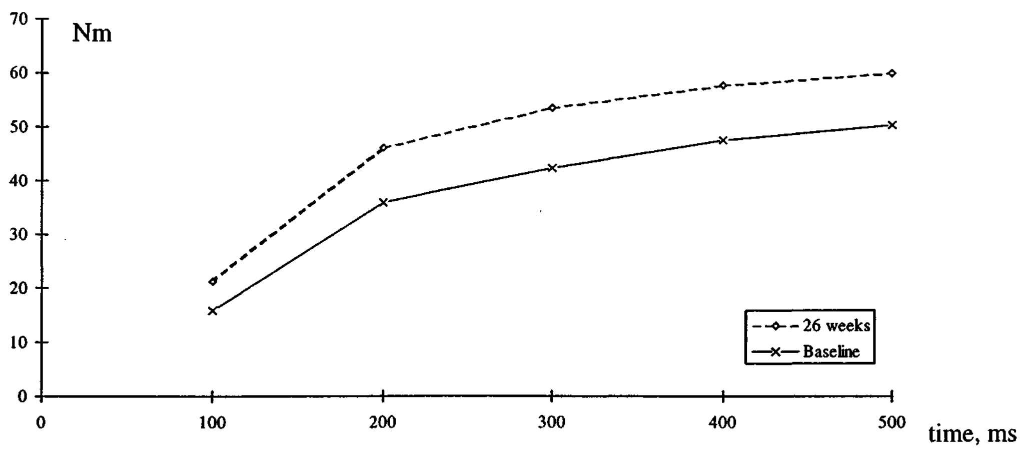

Figure 6a Averaged force-time curves for isometric elbow flexion torque for the exercise group

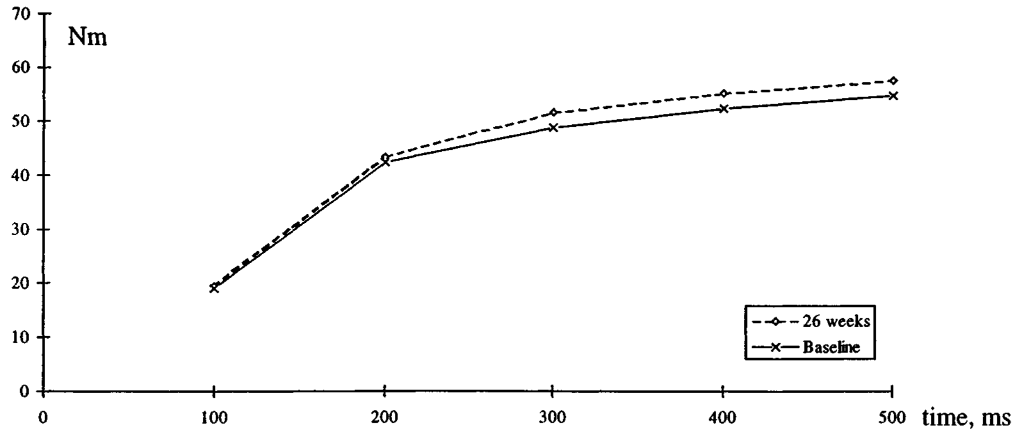

Figure 6b Averaged force-time curves for isometric elbow flexion torque for the estrogen group

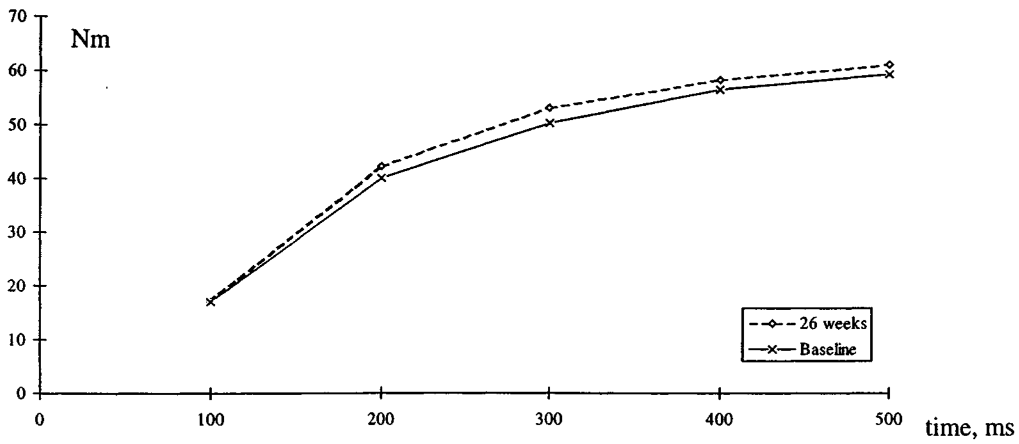

Figure 6c Averaged force-time curves for isometric elbow flexion torque for the exercise with estrogen group

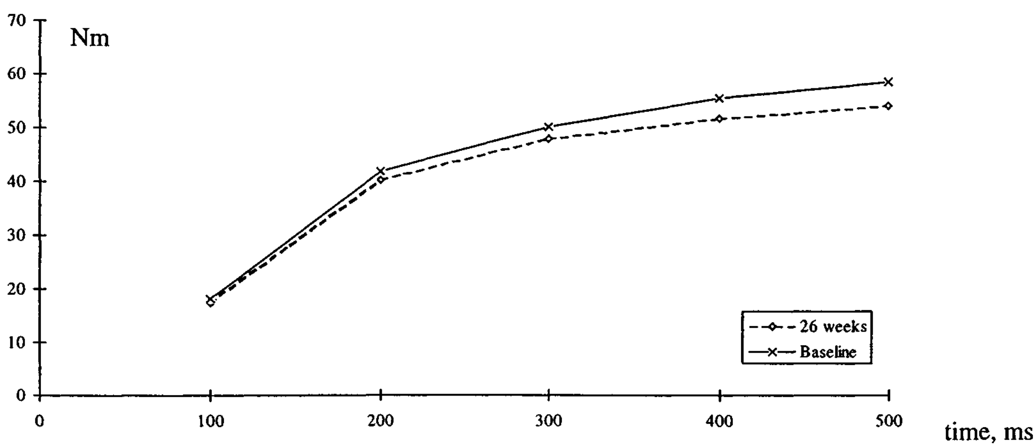

Figure 6d Averaged force-time curves for isometric elbow flexion torque for the control group

6 DISCUSSION

The results showed that plyometric training enhances isometric muscle strength of knee extension in postmenopausal women. The jumping type of training seems to enhance the speed of force production as well. The plyometric training showed to be well tolerated with previously sedentary postmenopausal women. In addition, some increase was observed in the isometric elbow flexion strength after 26 weeks of dynamic strength training. Estrogen alone may also increase muscle strength, however, no additive effect of exercise and estrogen was observed. The results indicate that a plyometric and dynamic strength training regimen might be used more widely and also adapted for home-based training i.e. aerobics.

Related to our specific plyometric training regimen used, Wilson et al. (1993) found that plyometric training enhanced only a counter moving jump, i.e. not isometric strength in current weight training males. The study group of weight trainees continuing with weight training according to study instructions seemed to enhance each force parameter tested. However, Wilson et al. (1993) suggested performance gains may be optimized by the use of plyometric weight training at a training load that maximizes the mechanical power output of the exercise. The controversial results of Wilson et al. (1993), might be explained by the history of weight training among men studied, or the different force characteristics of males related to the testosterone hormone.

For my aims to study the literature in this topics has shown 26 weeks to be time enough for supposed strength improvements in postmenopausal women (Brown et al. 1997, Heislein et al. 1994). The strength of hand grip was not enhanced, and elbow flexion was enhanced only in exercise and estrogen groups after 26 weeks of training. The possible explanation is that once per week of dynamic strength training for upper extremities is not sufficient. This is in accordance with common suggestions that two to three times per week of strength training is needed to achieve strength gain. However, supervised training sessions were provided several times per week to accomplish a good compliance and training frequency of two times per week. Although, we had five upper extremity exercises for circuit training, it might have been more effective, in terms of strength gain, to have only three upper extremity exercises to ensure the required exposure. When considering the training program, the plyometric strength training was held constant through out the 26 weeks, and the availability of five upper extremity exercises was chosen for some internal variability to the training.

In considering our strength results of elbow flexion and hand grip, the level of resistance might provide a useful explanation to the maintained level of isometric strength. The training program used was nonspecific. Only the biceps curl directly enhanced both the elbow flexion and the hand grip. Other exercise routines involved the grip hold but did not stress directly either the elbow flexor or hand grip strength. The resistance at 60%-80% of 1RM should have been enough to enhance strength. The repetitions were done at a rate of 10 per session, per exercise routine. Perhaps that was not enough to gain strength in the upper extremities during 26 weeks of dynamic strength training. There have been several other studies stressing the same training frequency and level of resistance, even though the test regimen used had been some what different (Charette et al. 1991, Lexell et al. 1995, Morganti et al. 1995, Pyka et al. 1994).

The question arises, is 26 weeks of dynamic and plyometric strength training long enough to increase strength and affect anthropometric factors? Previous studies have shown that changes in isometric strength are seen after 6 to 12 weeks of training (Charette et al. 1991, Doherty & Campagna 1993, Heislein et al. 1994, Häkkinen & Häkkinen 1995, Häkkinen et al. 1996). Lexell et al. (1995) have shown 1RM to increase after one year of heavy resistance (85% of one repetition maximum) training. During that year, after 11 weeks of training, the increase of strength was high (over 50%). For the following 27 weeks with one training session per week, strength was maintained. After the final 11 weeks of training strength was further increased. The difficulty in comparing these results to ours, is the difference in testing regimen used. In our results of isometric strength, the increase was seen in knee extension, but not in other muscle groups. If we consider our 1RM results, they are in accordance with results of Lexell et al. (1995).

Morganti et al. (1995) found strength improving in a stepwise fashion i.e. the study demonstrated great gains in strength after 8-12 weeks of high-intensity progressive training and smaller (significant) gains continued for at least another 44 weeks. They suggested to include with a training intervention a relatively high intensity of the training stimulus, frequent 1RM measurements to maintain desired stimulus intensity, and attempts to increase the training load each session according to individuals' perceived exertion and individualized training. These criterion were met in our study and also the results of 1RM testing seem to be related.

Pyka et al. (1994) found significant strength changes after 15 weeks of training in their year-long resistance training program. This difference persisted through 30 weeks, and among those exercisers who completed 52 weeks of training. These results seem to support our findings that the compliance with the study training program maintains an increase in strength.

In our study, the estrogen replacement therapy seemed to enhance increase in the strength results after 26 weeks of plyometric training. The effects of estrogen to strength on postmenopausal women have been controversial. Some previous studies have not seen the effect (Brown et al. 1997, Taaffe et al. 1995) while others did (Cauley et al. 1987, Heikkinen et al. 1997). In the study of Phillips et al. (1993) with rats and human, there was a reduction in isometric force in old age where muscles were deficient in sex hormone. They postulated that, it might not be a direct effect of estrogen, but related to growth hormone or insulin-like growth factor. In association with this, Phillips et al. (1993b) found decrease in specific force (the action of an unknown factor) in postmenopausal women to be prevented by estrogen replacement therapy. It remained a possibility that hormonal influences could alter the sensitivity of the cross-bridges to metabolites or that some other factors affects the cross-bridges reducing force development with aging.

Contradicting our study, and those mentioned previously, of estrogen replacement therapy, Taaffe et al. (1995) found that with elderly (65-82 years) women estrogen replacement had no effect on lower-body muscle strength. There was no exercise intervention, but subjects were controlled for in terms of their age of menopause (48 years-old) and exposure to estrogen replacement therapy (over 17 years). Considering this, it might suggest that the estrogen replacement itself, does not augment muscle strength. However, according to us and others (Cauley et al. 1987, Heikkinen et al. 1997) estrogen replacement with exercising might be useful for enhancing or at least maintaining muscle strength of postmenopausal women.

No changes in anthropometric properties were observed after 6 to 18 weeks of strength training in previous studies of elderly women (Charette et al. 1991, Grove & Londeree 1992, Sipilä et al. 1996) or after 12 months of strength training (Nelson et al. 1994). In agreement with this study, Häkkinen & Häkkinen found a significant decrease in percentage body fat during the 12 week training period in 50-70 year old males and females. The training consisted of explosive type training 2 times per week for most of the study. If we generalize, twice a week for one hour of dynamic and plyometric strength training does not increase the caloric expenditure to result in a loss of body fat. A reasonable question is, was 26 weeks of training time enough to decrease body fat? One must keep in mind the one percent decrease in the exercise with estrogen group. Even without statistical significance, this seemed indicative and emphasized the time effects of estrogen replacement. Furthermore, if there was enough time to see an effect of exercise on body fat, was there enough time for estrogen replacement to have an effect?

Another possible explanation for decreased body fat may exist in the increase of home training. All the study groups seem to increased their physical activity at home. This mainly endurance type training might affected the body fat. The study home exercise program was done at home, consequently increasing the former level of physical activity. Seasonal variation in eating habits as well in physical activities may have been factors to affect body fat.

There are some restrictions or underlying factors in isometric muscle strength testing. Postmenopausal women or women in their fifties, represent a culture all of their own. Women are not used to producing maximal effort in muscle work. This might be seen in strength tests, which were enhanced in each study group, and most of all in the two groups involved with supervised training sessions. The learning effect might not have been seen within a testing situation, but was seen between the pre- and post-tests. The given instructions and encouragement were standardized. The same examiners tested both pre- and post-tests and so the test situation was well controlled and reliable. The custom made test chair had been tested beforehand for reliability and validity (Sipilä et al. 1991). In addition, isometric strength testing is a widely used testing regimen and safe for subjects (i.e. the fixations used and the mode of force production without movement provides no torsion to joints or no requirement of highly skilled movement control). By getting familiar with the test regimen, women might be more capable of producing maximal effort as requested. This is without our exact knowledge, but should be considered when interpreting the results, i.e. the difference between study groups might be affected by this.

The idea of home training diaries partly succeeded. The training groups were instructed to do home exercises according to a home training program for this study. This exercising, if done or not, was not reported in home training diaries. The compliance of the home training program remains unknown. This is in agreement with previous studies, which have shown that home training (when given instructions) is not followed as requested. Sedentary people are not usually familiar with monitoring their physical activity by writing it up. This may have influenced the reported levels of physical activity in the home training diaries. However, the voluntary physical activity (i.e. the activities women continued during the study) were reported well and there were very few diaries missing for analysis.

All the study groups seemed to increase their previous level of physical activity. This may have influenced our results of isometric strength. However, the most popular modes of exercising were more or less related to endurance type of training, such as walking, cycling and cross-country skiing. When comparing our isometric strength results and increased physical activities, there exist a relation between knee extension strength and physical activity modes. It is a well known fact that, among athletes endurance type training might affect strength results by decreasing force production capabilities. This contradicts our isometric strength results. The self-reported levels (according to initial and 26 weeks questionnaires) of physical activity had not increased significantly, this might suggest that women got more used to physical activities, or the time of season affected the habits of leisure time activities.

This study had some key strengths. The sample of subjects was population based, and consequently selection bias should be avoided. There was also a strict randomization used to subgroup the subjects. The testing was conducted by the same testers each time and no specific attention was paid to different study groups. The training at home and at supervised training sessions was collected via training diaries, which provided the possibility to control for physical activity two months before and during the study. The subjects were provided several options to attend supervised training sessions in order to keep levels of compliance for training high. Even this succeeded although only partly, and the level of compliance was acceptable (71%), corresponding similar exercise interventions (Bloomfield et al. 1993, Charette et al. 1991, Heislein et al. 1994, Kriska et al. 1986, Lexell et al. 1995, Nelson et al. 1994, Presinger et al. 1995). However, related to our population based sample of women, the non-biased selection might have affected the compliance of the study. The former non-trained women might have felt stressed or had previously developed attitude against exercising, even with no experience of our study. This may have decreased the attendance to the supervised training sessions and home training.

The training program, even very specific and not familiar in nature, showed to be successful. There were no complaints about injuries during the 26 weeks of training. Jumping exercises seemed to provide "easy" feedback when the heights of hurdles were increased. The training groups offered an opportunity for social communication within their own peer group, so the training was completed with enthusiasm. One must keep in mind that in this generation women may have duties at work and at home. Even without former experience of physical exercising, most found it pleasurable and enjoyed it when noticed how their capabilities were enhanced with physical activities.

For future studies it would be interesting to reveal effects of plyometric training tested by isokinetic devices with high velocity. This might further clarify the special force production parameters supposedly enhanced by plyometric training. The training programs that include plyometrics should be area of interest for more studies and development. In addition to that, one could study the effects of an external load (i.e. free weights or weighted vests) on plyometric training of former sedentary women.

7 TIIVISTELMÄ

Tässä tutkimuksessa selvitettiin 26 viikon dynaamisen ja plyometrisen harjoittelun sekä estrogeenikorvaushoidon vaikutuksia postmenopausaalisten naisten isometriseen lihasvoimaan. Alkumittausten jälkeen 80 naista jaettiin satunnaistetusti liikunta-, liikunta ja estrogeeni-, estrogeeni- ja kontrolliryhmään. Estrogeenikorvaushoito toteutettiin kaksoissokkoutetusti. Isometrinen polven ojennus-, kyynärnivelen koukistus- ja käden puristusvoima tutkittiin dominoivalta puolelta. Keskimääräinen harjoitteluun osallistumisprosentti oli 71. Kehon rasvaprosentti laski merkitsevästi harjoitus- ja estrogeeniryhmässä verrattuna kontrolliryhmään. Polven maksimaalisessa isometrisessä ojennusvoimassa ($p = 0.043$), vääntömomenttissa ($p = 0.016$) ja painoon suhteutetussa vääntömomenttissa ($p = 0.011$) ajan ja ryhmän yhdysvaikutus oli merkitsevä. Polven voima- ja vääntömomenttimuutokset olivat merkitsevästi suurempia liikunta- ja estrogeeniryhmissä verrattuna kontrolliryhmään. Polven ojennuksen voimantuottonopeus lisääntyi tutkimusryhmissä merkitsevästi ensimmäisten 200-500 ms aikana ($p < 0.001$). Kyynärnivelen maksimaalinen koukistusvoima lisääntyi merkitsevästi liikunta- ja estrogeeniryhmissä verrattuna kontrolliryhmään. Kyynärnivelen koukistusvoima lisääntyi tilastollisesti merkitsevästi 300-500 ms aikana ($p < 0.05$) liikunta- ja estrogeeniryhmissä verrattuna kontrolliryhmään. Käden maksimaalinen puristusvoima ei muuttunut merkitsevästi 26 viikon harjoittelun ja estrogeenikorvaushoidon vaikutuksesta. Käden puristusvoiman voimantuottonopeus kasvoi liikunta- ja estrogeeniryhmissä ensimmäisten 100-200 ms aikana ($p < 0.005$) ja myös 300 ms kohdalla ($p = 0.03$). Tutkimusryhmäläisten vapaa-ajan fyysinen aktiivisuus lisääntyi 26 viikon aikana merkitsevästi, kun tutkimusinterventio jätetään mukaan laskematta. Tulokset osoittavat, että postmenopausaaliset, aiemmin vähän liikuntaa harrastaneet naiset kestävät hyvin plyometristä harjoittelua ja se kehittää isometristä polven ojennusvoimaa. Myös estrogeenikorvaushoito vaikuttaa osaltaan polven ojennusvoiman lisääntymiseen.

Avainsanat: postmenopaussi; plyometrinen harjoittelu; voimaharjoittelu; isometrinen lihasvoima; estrogeeni

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9 APPENDIXES

Appendix 1 The supervised circuit training diary, "Harjoituspäiväkirja"

Appendix 2 The home training diary, "Liikuntapäiväkirja"

Appendix 1

Exercise and estrogen replacement study, 1996-1997

Harjoituspäiväkirja

Nimi: ______________________________

Osallistumiseni aerobics-tunneille viikoilla 4 ja 5

Viikolla 4 ________ kertaa

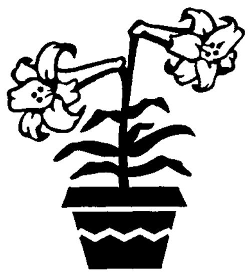
Viikolla 5 ________ kertaa

Viikko 8

	1	2
Pystypunnerrus	____kg ___x___	_____kg ____x____
1 RM ______ kg		
Huom. ____________________		Huom. ____________
Rintalihakset	____kg ___x___	_____kg ____x____
1 RM ______ kg		
Huom. ____________________		Huom. ____________
Soutu	____kg ___x___	_____kg ____x____
1 RM ______ kg		
Huom. ____________________		Huom. ____________
Talja	____kg ___x___	_____kg ____x____
1 RM ______ kg		
Huom. ____________________		Huom. ____________
Hauisvääntö	____kg ___x___	_____kg ____x____
1 RM ______ kg		
Huom. ____________________		Huom. ____________

Hyppelyharjoittelu

Hyppynaru	________ s	Huom. ____________
Esteet	________ cm	Huom. ____________
Pudotushyppy	________ cm	Huom. ____________
Yhdellä jalalla hyppy	________ krt	Huom. ____________



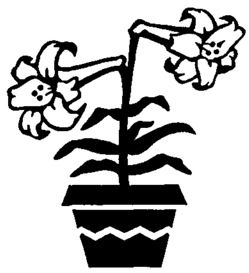
_______________ KUNTOPIIRIKIERROSTA

Viikko 9

	1	2
Pystypunnerrus	____kg ___x___	_____kg ____x____
1 RM ______ kg		
Huom. ____________________________		Huom. _________________
Rintalihakset	____kg ___x___	_____kg ____x____
1 RM ______ kg		
Huom. ____________________________		Huom. _________________
Soutu	____kg ___x___	_____kg ____x____
1 RM ______ kg		
Huom. ____________________________		Huom. _________________
Talja	____kg ___x___	_____kg ____x____
1 RM ______ kg		
Huom. ____________________________		Huom. _________________
Hauisvääntö	____kg ___x___	_____kg ____x____
1 RM ______ kg		
Huom. ____________________________		Huom. _________________

Hyppelyharjoittelu

Hyppynaru	________ s	Huom. _________________
Esteet	________ cm	Huom. _________________
Pudotushyppy	________ cm	Huom. _________________
Yhdellä jalalla hyppy	________ krt	Huom. _________________



_______________ KUNTOPIIRIKIERROSTA

Appendix 2

Exercise and estrogen replacement study, 1997.

Liikuntapäiväkirja.

Nimi: ______________________________

Pyydämme Teitä ystävällisesti pitämään päiväkirjaa tavanomaisesta liikunnastanne. Lomakkeeseen tulisi merkitä kaikki liikunta, jota Teidän on tapana harrastaa kuntonne kohottamiseksi ja ylläpitämiseksi. Merkitkää asianomaisten päivien kohdalle mahdollisimman tarkkaan liikuntamuodot, liikunnan kesto ja mahdolliset muut liikuntaa kuvaavat huomautukset. Tutkimuksemme kannalta olisi tärkeää, että **liikuntatottumuksenne eivät muuttuisi** siitä, mitä ne olivat ennen tutkimusta. Mikäli Teillä on kysyttävää tutkimuksestamme, pyydämme Teitä soittamaan numeroon 602165 (Harri Suominen) tai 602179 (Sarianna Sipilä).

<u>Esimerkki.</u>

Päivämäärä	**Liikuntamuoto**	**Liikunnan kesto (minuuteissa)**	**Muita Huomioita**
Helmikuu			
La 1.	______________	______________	______________
Su 2.	______________	______________	______________

Päivämäärä	Liikuntamuoto	Liikunnan kesto (minuuteissa)	Muita Huomioita
Kesäkuu			
Su 1.			
Ma 2.			
Ti 3.			
Ke 4.			
To 5.			
Pe 6.			
La 7.			
Su 8.			
Ma 9.			
Ti 10.			
Ke 11.			
To 12.			
Pe 13.			
La 14.			
Su 15.			
Ma 16.			
Ti 17.			
Ke 18.			
To 19.			
Pe 20.			
La 21.			
Su 22.			

Päivämäärä	Liikuntamuoto	Liikunnan kesto (minuuteissa)	Muita Huomioita
Ma 23			
Ti 24.			
Ke 25.			
To 26.			
Pe 27.			
La 28.			
Su 29.			
Ma 30.			

Heinäkuu

Ti 1.			
Ke 2.			
To 3.			
Pe 4.			
La 5.			
Su 6.			
Ma 7.			
Ti 8.			
Ke 9.			
To 10.			
Pe 11.			
La 12.			
Su 13.			