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Effect of Exercise Training on Physical Activity and Substrate Utilization in the Elderly

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This study examined the effect of training on physical activity and substrate utilization in the elderly. Before the start, in week 6 and week 12 (T0, T6 and T12) data on physical fitness, physical activity and substrate utilization were collected in the exercise (11 males, 11 females; 63 ± 8 yrs) and control group (6 males, 5 females; 59 ± 4 yrs). Physical activity was registered with a tri-axial accelerometer and substrate utilization was calculated from resting respiratory exchange ratio (RER) by indirect calorimetry. At T6 physical activity on training days was significantly higher than on non-training days (33.4 ± 10.3 vs. 26.5 ± 7.8 counts · min^{-1}; $p < 0.001$). At T12, after adjusting for training activity, physical activity on training days was significantly lower than on non-training days (23.7 ± 8.4 vs. 28.2 ± 9.3 counts · min^{-1}; $p < 0.01$). RER decreased significantly (0.02 ± 0.03; $p < 0.05$), indicating a relatively larger fat oxidation. Changes in RER were negatively correlated with pre-training RER. In conclusion, in elderly an increase in structured training (exercise) is compensated for by a corresponding decrease in non-training physical activity. Training increased relative fat utilization in elderly with a high pre-training RER, whereas elderly with a low pre-training RER decreased their relative fat utilization.

Key words: Tri-axial accelerometer, metabolic rate, physical fitness.

Introduction

Exercise programs for the elderly are promoted to improve or maintain physical fitness and health. It is generally believed that an improved physical fitness would increase the daily level of physical activity. Recently, however, three studies in the elderly reported a decrease in non-training physical activity as a consequence of participation in an exercise training program [9,13,15]. Morio et al. [15] measured the effect of training on non-training physical activity by using 7-day activity recordings. Non-training physical activity was calculated from the duration and unitary costs of the various recorded activities. Goran and Poehlman [9] calculated non-training physical activity from the difference between total energy expenditure and resting energy expenditure after adjusting for the thermic response to feeding and the energy cost of the exercise training. Meijer et al. [13], directly measured non-training physical activity with a tri-axial accelerometer.

Assessment of physical activity patterns in subjects by using body-fixed accelerometers seems to offer promising possibilities. Bouten et al. [5] developed a tri-axial accelerometer based on three separate uni-axial accelerometers. Comparison between physical activity generated accelerometer output and activity associated energy expenditure as measured with doubly labeled water in 30 free living subjects over 7-day intervals revealed a significant relationship ([4]; $r = 0.79$).

Aging is generally associated with an increase in adiposity and loss of fat-free mass, which could be partially explained by a decreased physical activity and declining resting metabolic rate [1,7,10]. It has also been suggested that elevated levels of body fat in the elderly may be due, at least partially, to a decrease in fat mobilization [11]. Therefore, an exercise intervention to increase fat oxidation may be beneficial in reducing obesity in the elderly. Three studies examined the effect of exercise training on fat utilization in rest in the elderly [16,19, 22]. These studies used respiratory exchange ratio (RER) as a marker for fat utilization. Two studies [16,22] demonstrated an increase, and Sial et al. [19] reported no significant change in resting fat utilization. Treuth et al. [22] demonstrated an increased fat oxidation, as calculated from RER, after 16-wk strength training. Poehlman et al. [16], also showed an increased fat oxidation during rest as measured with the [^{14}C]palmitate infusion method, after 8-wk endurance training. Sial et al. [19], on the other hand, demonstrated only a training-induced increase in fat utilization during exercise as measured with stable isotope tracers. The differences between those three studies could partly be explained by differences in standardization.

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Although it seems that training influences resting fat oxidation, Van Etten et al. [23] demonstrated in young adults that training induced changes in RER were negatively correlated with pre-training RER values. This suggests that training increases fat utilization in subjects with a high pre-training RER, whereas fat utilization decreases in subjects displaying low pre-training RER.

The purpose of this study was to investigate the effect of a 12-wk exercise training program of moderate intensity on daily physical activity and substrate utilization in the elderly. Physical activity was registered by using a tri-axial accelerometer. RER was used as a measure for substrate utilization.

Methods

Subjects

Thirty-three healthy sedentary men and women, over 55 yrs of age, were selected to participate in the study. Detailed information concerning the purpose and methods used in the study was provided, and written consent was obtained. Twenty-two subjects (11 women, 11 men) participated in the exercise group (EXER), and eleven subjects (5 women, 6 men) served as non-trained controls (CONT). The variables body composition, basal metabolic rate (BMR), daily physical activity and physical fitness were measured at T0 (baseline), at T6 (6-wk training) and T12 (12-wk training) in EXER and at T0 and T12 in CONT.

Body composition

Physical characteristics are shown in Table **1**. Anthropometric measurements were taken after an overnight stay at the laboratory. After voiding, body mass was measured on an electronic scale (Sauter, Type E1200, Albstadt 1, Ebingen, Germany). Body volume was determined with underwater weighing. Residual lung volume was simultaneously measured with the helium dilution technique (Volugraph 2000, Mijnhardt, Bunnik, The Netherlands). Total body water (TBW) was determined with deuterium (^2H_2O) dilution [12]. Body composition was calculated from body mass, body volume and TBW with the three-compartment model of Siri [20].

Table 1 Characteristics of the exercise (EXER) and control group (CONT)

	EXER	CONT
number (men/women)	22 (11/11)	11 (6/5)
age, yrs	63 ± 8	59 ± 4
height, m	1.69 ± 0.09	1.70 ± 0.10
body mass, kg	81.6 ± 16.1	75.1 ± 13.3
BMI, kg·m^{-2}	29 ± 4	26 ± 3
Fat, %	37 ± 7	33 ± 7
Fat mass, kg	29.9 ± 8.4	24.6 ± 6.9
Fat-free mass, kg	51.6 ± 11.2	50.5 ± 9.7
$\dot{V}O_{2max}$, l·min^{-1}	1.91 ± 0.44	2.02 ± 0.36
W_{max}, watt	126 ± 33	144 ± 28
HR_{max}, bts·min^{-1}	141 ± 18	149 ± 14

Results are means ± SD. Analysis revealed no differences between the groups

Basal metabolic rate

Basal metabolic rate (BMR) was measured after an overnight fast for 30-min at 7.00 a.m. Due to limited use of the respiration chamber only fifteen subjects slept at the laboratory, the other 18 subjects were transported to the laboratory by car to reduce physical activity. Subjects driven to the laboratory at T0, were also driven to the laboratory at T6 and T12. BMR was measured for at least 15-min under thermoneutral temperature conditions, after a period of 15-min bedrest. Oxygen consumption and carbon dioxide production were measured by means of a computerized, open-circuit, ventilated hood system. Gas analyses were performed using a paramagnetic oxygen analyzer (Servomex Type 500A, Crowborough Sussex, UK) and an infrared carbon dioxide analyzer (Servomex Type 12-Xi). The system was similar to the analysis system for the respiration chambers described before [17]. Calculation of BMR was based upon the Weir formula [25].

Sleeping metabolic rate

Sleeping metabolic rate (SMR) was measured during an overnight stay in a respiration chamber (8.00 p.m.: 7.00 a.m.) as described before [18]. To minimize the residual effects of training on energy expenditure, subjects were measured 36 hours after the last training session. SMR was measured over a shiftable 3-h interval between 0.00 – 6.00 a.m. with the minimal activity level judged from Doppler radar observation. SMR was measured in 10 subjects randomly selected from the exercise group and 5 subjects randomly selected from the control group.

Daily physical activity

Physical activity over a 14-day interval was registered by using a tri-axial accelerometer, consisting of three uni-axial piezoelectric accelerometers, attached to the lower back of the subjects with an elastic belt. The tri-axial accelerometer was the same version (69 × 28 × 9 mm, 30 gram) as described recently [13,27]. The accelerometer calculates the sum of the rectified and integrated acceleration curves from the antero-posterior, medio-lateral and longitudinal axis of the trunk. The time period for integration was set at 1min. Subjects were instructed to wear the accelerometer during waking hours, except during bathing and showering.

Physical fitness

To investigate the effect of the training program on aerobic power (maximal oxygen uptake: $\dot{V}O_2$max) and maximal power output (W_{max}), an incremental exercise test was performed on an electromagnetically braked cycle ergometer (Lode Excalibur, Groningen, The Netherlands). Subjects started to cycle 3-min at 30 W at 60 rpm and the workload was increased every minute with 10 W until exhaustion. Criteria for maximal aerobic performance were forced ventilation, leveling off of oxygen uptake or a respiratory exchange ratio (RER) above 1.1. The oxygen uptake during the test was measured continuously, using a computerized open system (SensorMedics 2900 analyzer, Anaheim, CA, USA). During the incremental exercise test heart rate was continuously measured (Polar Sport Tester, Kempele, Finland). To quantify the effect of the training program on the heart function, heart rate at a submaximal power output of 100 W and 70 W were compared before and after training.

Training program

The subjects trained twice a week at a fitness club, on one day a group session of 60-min with various aerobic exercises and another day an individual session of 90-min consisting of 9 exercises using cardio- and weight-stack machines (Sportesse, Germany). Two sets of 10 repetitions were performed of the following exercises: lat row (m. latissimus dorsi), pec deck (m. pectoralis major/minor), leg extension (quadriceps femoris), leg curl (hamstrings), biceps curl, triceps extension, shoulder press (m. deltoidius) and sit-ups (abdominal muscles). Additionally, each individual session included a 10-min warming-up and cooling down of walking or cycling on a self selected intensity. The group session consisted of 15-min warming-up with non-intensive aerobic running and stretching exercises, followed by 30-min step exercise. Each group session was concluded by 15-min cooling down period during which low intensity aerobic and relaxation exercises were conducted. The group session was chosen to improve compliance. The intensity of both training sessions was approximately 50% of heart rate reserve as measured by heart rate (Polar Sport Tester, Kempele, Finland) and a slight progressive training design was used. Average training compliance was 86 ± 8%. A fitness instructor supervised the training sessions.

Statistics

The analysis of variance (ANOVA) for repeated measures within subjects was used to compare differences in EXER. Paired t-tests were used to analyze differences in CONT between baseline measurements and T12. To analyze differences between the exercise and control group regarding SMR and RER, the non-parametric Mann-Whitney U test was used. Statistical significance was set at $p < 0.05$.

Results

Body composition

In both groups, EXER and CONT, subjects showed no change in body mass (Table **2**). There were no changes in body composition in EXER (T0, T6 and T12: 37 ± 7, 36 ± 7 and 36 ± 7% fat mass) and in CONT (T0 and T12: 33 ± 7 and 32 ± 7% fat mass). Gender had no significant effect on the explained variation of the effect of training on physical fitness, physical activity and substrate utilization.

Table 2 Changes in body composition, basal metabolic rate and physical fitness in the exercise (EXER), and in the control group (CONT)

	EXER		CONT
	T6	T12	T12
body mass, kg	– 0.2 ± 1.7	– 0.3 ± 2.0	0.6 ± 0.9
fat, %	– 0.6 ± 2.0	– 0.3 ± 1.7	– 0.9 ± 2.2
Fat-free mass	0.54 ± 0.43	0.14 ± 1.60	1.31 ± 2.10
BMR, $kJ \cdot min^{-1}$	– 0.2 ± 0.4**	– 0.2 ± 0.5*	– 0.1 ± 0.4
$\dot{V}O_2max$, $l \cdot min^{-1}$	0.17 ± 0.25*	0.16 ± 0.34*	0.05 ± 0.21
W_{max}, watt	6 ± 17*	9 ± 20*	0 ± 10
HR 100 W, $bts \cdot min^{-1}$	– 8 ± 11**	– 10 ± 11**	– 1 ± 6***
HR 70 W, $bts \cdot min^{-1}$	– 6 ± 11*	– 9 ± 11*	– 1 ± 9***

Significantly different from T0: * $p < 0.05$; ** $p < 0.001$. Significantly different between the groups: *** $p < 0.001$

Metabolic rate

BMR significantly decreased in EXER (T0 vs. T6 and T12: 4.9 ± 1.1 vs. 4.6 ± 1.0 and 4.7 ± 0.9 $kJ \cdot min^{-1}$; $p < 0.01$ and $p < 0.05$), whereas, there were no changes in BMR in CONT (T0 and T12: 4.8 ± 0.6 and 4.7 ± 0.7 $kJ \cdot min^{-1}$). BMR adjusted for FFM, also significantly decreased in EXER (T0 vs. T6 and T12: 95 ± 13 vs. 90 ± 13 and 91 ± 10 $J \cdot min^{-1} \cdot kg^{-1}$; $p < 0.01$ and $p < 0.05$). No changes were shown in CONT (T0 vs. T12: 97 ± 10 vs. 93 ± 11 $J \cdot min^{-1} \cdot kg^{-1}$). SMR adjusted for FFM, measured in a subgroup of EXER (n = 10), significantly decreased (T0 vs. T6 and T12: 93 ± 9 vs. 84 ± 8 and 88 ± 6 $J \cdot min^{-1} \cdot kg^{-1}$; $p < 0.05$ and $p = 0.06$). No changes in SMR, measured in a subgroup of CONT (n = 5), were shown (T0 and T12: 91 ± 11 and 90 ± 11 $J \cdot min^{-1} \cdot kg^{-1}$).

Substrate utilization

The decrease in RER_{SMR} in EXER at T12 (0.80 ± 0.03 vs. 0.78 ± 0.03; $p < 0.05$) indicated an increased fat oxidation. However, RER_{BMR} in EXER at T12, remained unchanged. In CONT no changes in RER_{SMR} or in RER_{BMR} were observed. Changes in RER_{BMR} and RER_{SMR} at T12 were negatively correlated with the pre-training RER ($r = -0.62$ and $r = -0.64$; $p < 0.01$ and $p < 0.05$), Fig. **1**). No such relationship was observed in CONT.

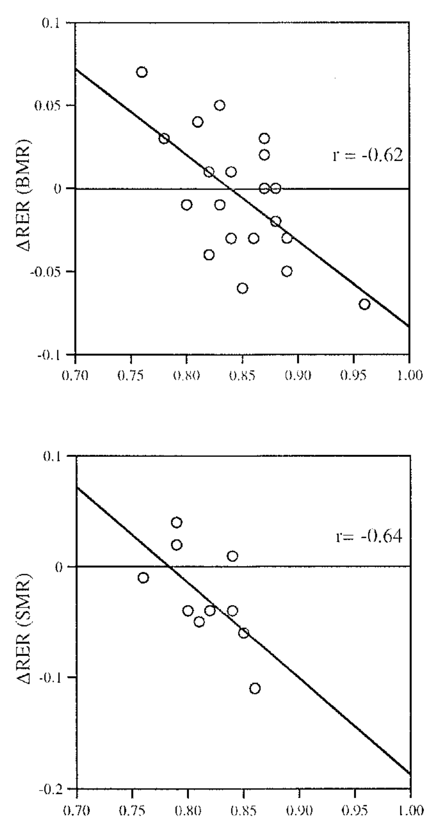

Fig. 1 Relationship between respiratory exchange ratio (ΔRER) and pre-training RER measured during BMR ($p < 0.01$) and SMR ($p < 0.05$).

a, b

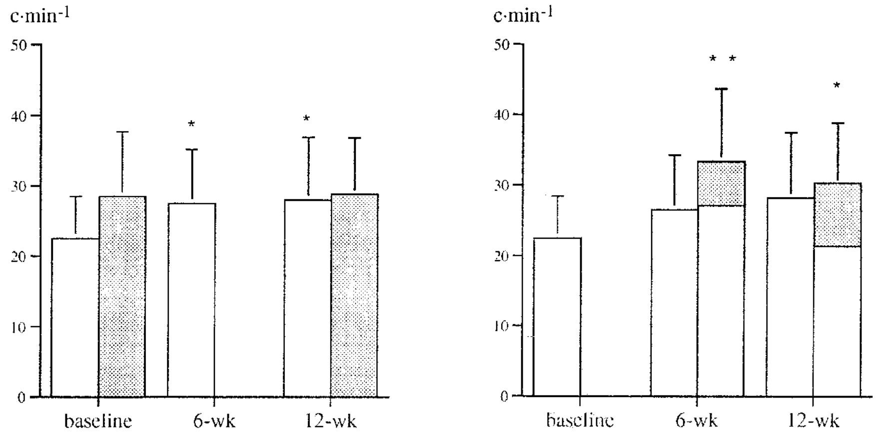

Fig. 2 **a** Daily accelerometer output (mean ± SD) in counts · min^{-1}. Accelerometer output does not differ between the exercise group (EXER; open bars) and the control group (CONT; filled bars). Significantly different from T0 (*$p < 0.05$).
b Accelerometer output (mean ± SD) on training and non-training days in counts · min^{-1}. Contribution accelerometer output of training session (filled squares). Significantly different between training and non-training days (**$p < 0.001$). Significantly different between non-training days and training days minus training session (*$p < 0.01$).

Daily physical activity

As depicted in Fig. **2a**, average daily physical activity as measured with the tri-axial accelerometer over two-week intervals significantly increased in EXER (T6 and T12 vs. T0: 27.5 ± 7.7 and 28.0 ± 8.9 vs. 22.5 ± 6.0 counts · min^{-1}; $p < 0.05$). No change in physcial activity was observed in CONT (T0 and T12: 28.5 ± 9.2 and 28.8 ± 8.0 counts · min^{-1}). AT T6 physical activity was significantly higher on training days than on non-training days (33.4 ± 10.3 vs. 26.5 ± 7.8 counts · min^{-1}; $p < 0.001$; Fig. **2b**), whereas, at T12, there was no significant difference between physical activity on training and non-training days (30.1 ± 8.8 vs. 28.2 ± 9.3 counts · min^{-1}). After subtracting the accelerometer output of the training sessions from total accelerometer output on training days and after adjusting for training time, at T12 physical activity on training days was significantly lower than on non-training days (23.7 ± 8.4 vs. 28.2 ± 9.3 counts · min^{-1}; $p < 0.01$; Fig. **2b**). A training session resulted in an accelerometer output of 98 ± 28 counts · min^{-1} at T6 and 109 ± 17 counts · min^{-1} at T12 ($p < 0.05$). The time wearing the accelerometer did not change between T0, T6 and T12 in both groups (EXER: 865 ± 61, 870 ± 63, 881 ± 58 min · day^{-1} and CONT: 870 ± 69, 861 ± 81 min · day^{-1}).

Physical fitness

In Table **2** the differences in W_{max} and $\dot{V}O_2max$ measured at the incremental exercise test are presented for both groups. W_{max} and $\dot{V}O_2max$ at T12 increased significantly in EXER. In CONT no significant changes in W_{max} and $\dot{V}O_2max$ could be demonstrated. Heart rate at 100 W significantly reduced in EXER at T6 and T12 when compared with T0 (113 ± 17 and 111 ± 18 vs. 121 ± 20 bts · min^{-1}; $p < 0.01$), whereas heart rate at 100 W in CONT remained unchanged between T0 and T12 (125 ± 19 vs. 124 ± 21 bts · min^{-1}). Heart rate at 70 W, also reduced in EXER and remained unchanged in CONT (Table **2**).

Discussion

Physical activity

The present study was performed to examine the effect of exercise training on daily physical activity in healthy older individuals. Daily physical activity was registered over a two-week interval with a tri-axial accelerometer. Results show a significant increase in total physical activity, which is in accordance with findings of Meijer et al. [14] in young adults. They demonstrated that the increase in total physical activity was almost entirely the result of the added training for marathon running. Although the mode of exercise was different from the present study, the observed increase in total physical activity was similar. Overall, physical activity on training days was significantly higher than on non-training days. After subtracting the physical activity of the training session, however, the remaining physical activity was lower than on non-training days (Fig. **2**). The decline in non-training physical activity at T12 compared to T6 might be associated with an increased exercise intensity (109 ± 17 vs. 98 ± 28 counts · min^{-1}; $p < 0.05$), since subjects were not suffering from any injuries. The decline in non-training physical activity agrees with previous findings [9,13,15]. Goran and Poehlman [9] suggested that in their study the exercise intensity during the last week of training (3 h/wk at 85 % of VO_2max) fatigued the elderly participants during the remaining of the day. Meijer et al. [13], however, used an exercise training program of moderate intensity, and exercise training sessions were performed in the later afternoon. The same protocol was used in the present study.

Possibly, the duration of the exercise intervention might explain the observed decline in non-training physical activity, because in the present study only after 12-wk training a decline in non-training physical activity was observed. Goran and Poehlman [9] showed a decline after 8-wk endurance training. Probably, 6-wk exercise training of moderate intensity is too short to influence non-training physical activity. Because the exercise training sessions were performed during the late afternoon, the decline in non-training physical activity likely preceded the training sessions. Our results, therefore, suggest that the compensation in physical activity as a consequence of participation in an exercise training program seems to be an anticipatory mechanism, i.e. the elderly participants lowered their physical activity already before the exercise training sessions. Unfortunately, it is unknown at which time the training sessions were performed in the study of Goran and Poehlman [9]. From a clinical perspective, our results indicate that exercise prescribed to elderly people might reduce non-training physical activity.

Substrate utilization

During sleep or rest RER showed a significant decrease after the training period. Assuming an unchanged contribution of protein oxidation, the decline in RER indicates approximately a 7% increase in the magnitude of the fat oxidation. Previous studies suggested that the training-induced increase in resting fat oxidation is attributed to an increased activity of the sympathetic nervous system [16,19]. Poehlman et al. [16] demonstrated that endurance training increased norepinephrine appearance rate by 35% and that approximately 50% of the variation of the increase in fat oxidation was explained by norepinephrine appearance rate ($r^2 = 0.51$, $p < 0.01$). In the present study, it was demonstrated that the change in RER was inversely correlated with pre-training RER (Fig. **1**), which is in accordance with previous findings in young adults [23]. Subjects with a low pre-training RER increased their RER, whereas subjects with a high pre-training RER showed a decrease. We, as Van Etten et al. [23], have yet no idea what biological mechanism might explain this finding. Change in eating habit is not likely since RER may change in both directions. Furthermore, the high correlation between pre-training RER and ΔRER ($p < 0.01$) makes it less plausible that the change in RER was a consequence of regression to the mean.

Physical fitness

In the present study a significant increase in W_{max} and $\dot{V}O_2max$ was observed (Table **2**). The 8% increase in VO_2max after 12-wk exercise training (1.91 ± 0.44 vs. $2.07 \pm 0.59\ l \cdot min^{-1}$; $p < 0.05$) is similar to results of previous studies [17,21]. In elderly people, however, the accomplishment of daily activities corresponds better to submaximal responses to exercise training [8]. In the present study, the reduction in heart rate at a submaximal power output of 100 W rate after 12-wk training is in agreement with findings of De Vito et al. [8]. Thus, an exercise training program of moderate intensity twice a week, as used in the present study, improves physical fitness in healthy older adults.

Metabolic rate

The decreased SMR and BMR in EXER in the present study are in contrast with other exercise training intervention studies in the elderly [6,9]. Both studies demonstrated an increase in BMR. They measured BMR, as in the present study, at least 36 h after the last training session to prevent any carry-over effect from the prior exercise bout and both studies reported an increased fat-free mass. Although fat-free mass is an important determinant of BMR, most studies in young adults showed an exercise-induced increase in fat-free mass without an increase in BMR [2,3,24,26]. The longest training intervention study (40-wk endurance training) showed the largest absolute increase (5%) in fat-free mass with a slightly lower BMR [26]. The authors speculated that BMR was decreased to prevent a further decline in body mass, because body mass was significantly decreased with 1.0 ± 1.7 kg. In the present study body mass and body composition did not change. We have no explanation for the observed decline in BMR and SMR. It does not seem likely that the decrease in BMR was due to methodological bias since the same subjects were driven to the laboratory prior to the BMR test at T0, T6 and T12.

Body composition

The unchanged body mass is in accordance with other exercise training intervention studies [2,3,6,9,24]. However, these studies demonstrated a significant increase in fat-free mass and a decrease in fat mass without a change in body mass. Differences in training intervention (type of exercise) might explain the inconsistency in changes in body composition. In the present study two different training sessions were used, namely a group session with various aerobic exercises and an individual resistance training session. In the other studies, however, only an endurance training protocol was used [2,3, 9] or a resistance training protocol was used [6,24]. Furthermore, all studies used a training program of high intensity, whereas, in the present study, a training program of moderate intensity was used (50% heart rate reserve).

Conclusion

In conclusion, in elderly an increase in structured trianing (exercise) is compensated for by a corresponding decrease in non-training physical activity. Furthermore, the exercise training program decreased SMR and BMR and increased relative fat utilization in elderly with a high pre-training RER, whereas relative fat utilization decreased in elderly with a low pre-training RER.

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References

1 Bemben MG, Massey BH, Bemben DA, Boileau RA, Misner JE. Age-related patterns in body composition for men aged 20–79 yr. Med Sci Sports Exerc 1995; 27: 264–269
2 Bingham SA, Goldberg GR, Coward WA, Prentice AM, Cummings JH. The effect of exercise and improved physical fitness on basal metabolic rate. Br J Nutr 1989; 61: 155–173
3 Blaak EE, Westerterp KR, Bar-Or O, Wouters LJM, Saris WHM. Total energy expenditure and spontaneous activity in relation to training in obese boys. Am J Clin Nutr 1992; 55: 777–782
4 Bouten CVC, Verboeket-Van de Venne WPHG, Westerterp KR, Verduin M, Janssen JD. Daily physical activity assessment: comparison between movement registration and doubly labeled water. J Appl Physiol 1996; 81: 1019–1026
5 Bouten CVC, Westerterp KR, Verduin M, Janssen JD. Assessment of energy expenditure for physical activity using a triaxial accelerometer. Med Sci Sports Exerc 1994; 26: 1516–1523
6 Campbell WW, Crim MC, Young VR, Evans WJ. Increased energy requirements and changes in body composition with resistance training in older adults. Am J Clin Nutr 1994; 60: 167–175
7 Davy KP, Evans SL, Stevenson ET, Seals DR. Adiposity and regional body fat distribution in physically active young and middle-aged women. Int J Obes 1996; 20: 777–783
8 De Vito G, Hernandez R, Conzalez V, Felici F, Figura F. Low intensity physical training in older subjects. J Sports Med Phys Fitness 1997; 37: 72–77
9 Goran MI, Poehlman ET. Endurance training does not enhance total energy expenditure in healthy elderly persons. Am J Physiol 1992; 263: E950–E957
10 Kohrt WM, Malley MT, Dalsky DP, Holloszy JO. Body composition of healthy sedentary and trained, young and older men and women. Med Sci Sports Exerc 1992; 24: 832–837

[11] Lönnqvist F, Nyberg B, Wahrenberg H, Arner P. Catecholamine-induced lipolysis in adipose tissue fo the elderly. J Clin Invest 1990; 85: 1614 – 1621
[12] Marken Lichtenbelt WD, Westerterp KR, Wouters L. Deuterium dilution as a method for determining total body water: effect of test protocol and sampling time. Br J Nutr 1994; 72: 491 – 497
[13] Meijer EP, Westerterp KR, Verstappen FTJ. The effect of exercise training on total daily physical activity in the elderly. Eur J Appl Physiol 1999; 80: 16 – 21
[14] Meijer GAL, Janssen GME, Westerterp KR, Verhoeven F, Saris WHM. The effect of a 5-month endurance training programme on physical activity: evidence for a sex-difference in the metabolic response to exercise. Eur J Appl Physiol 1991; 62: 11 – 17
[15] Morio B, Montaurier C, Pickering G, Ritz P, Fellmann N, Coudert J, Beaufrere B, Vermorel M. Effects of 14 weeks of progressive endurance training on energy expenditure in elderly people. Br J Nutr 1998; 80: 511 – 519
[16] Poehlman ET, Gardner AW, Arciero PJ, Goran MI, Calles-Escadon J. Effects of endurance training on total fat oxidation in elderly persons. J Appl Physiol 1994; 76: 2281 – 2287
[17] Posner JD, Gorman KM, Windsor-Lansberg L, Larsen J, Bleiman M, Shaw C, Rosenberg B, Knebl J. Low to moderate intensity endurance training in healhty older adults: physiological responses after four months. J Am Geriatr Soc 1992; 40: 1 – 7
[18] Schoffelen PFM, Westerterp KR, Saris WHM, Ten Hoor F. A dual-respiration chamber system with automated calibration. J Appl Physiol 1997; 83: 2064 – 2072
[19] Sial S, Coggan AR, Hickner RC, Klein S. Training-induced alterations in fat and carbohydrate metabolism during exercise in elderly subjects. Am J Physiol 1998; 274: E785 – E790
[20] Siri WE. The gross composition of the body. Adv Biol Med Phys 1956; 4: 239
[21] Takeshima N, Tanaka K, Kobayashi F, Watanabe T, Kato T. Effects of aerobic exercise conditioning at intensities corresponding to lactate threshold in the elderly. Eur J Appl Physiol 1993; 67: 138 – 143
[22] Treuth MS, Hunter GR, Weinsier RL, Kell SH. Energy expenditure and substrate utilization in older women after strength training: 24-h calorimeter results. J Appl Physiol 1995; 78: 2140 – 2146
[23] Van Etten LMLA, Westerterp KR, Verstappen FTJ. Effect of weight-training on energy expenditure and substrate utilization during sleep. Med Sci Sports Exerc 1995; 27: 188 – 193
[24] Van Etten LMLA, Westerterp KR, Verstappen FTJ, Boon BJB, Saris WHM. Effect of an 18-week weight-training program on energy expenditure and physical activity. J Appl Physiol 1997; 82: 298 – 304
[25] Weir JB. New methods for calculating metabolic rate with special reference to predicting protein metabolism. J Physiol (London) 1949; 109: 1 – 9
[26] Westerterp KR, Meijer GAL, Schoffelen P, Janssen EME. Body mass, body composition and sleeping metabolic rate before, during and after endurance training. Eur J Appl Physiol 1994; 69: 203 – 208
[27] Westerterp KR. Physical activity assessment with accelerometers. Int J Obes 1999; 23: S45 – S49

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