Physical activity and parameters of aging: a physiological perspective.

Journals of Gerontology: SERIES A
2001, Vol. 56A (Special Issue II):7–12

Physical Activity and Parameters of Aging: A Physiological Perspective

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Increasing age is associated with a decline in fat-free mass. The question is whether age-related changes in body composition can be delayed by an active life style. This analysis includes data where physical activity was assessed with doubly labeled water and body composition with hydrodensitometry or isotope dilution. Subjects were 136 women and 180 men over 20 years, who were tested in Maastricht University between 1983 and 1998. Increasing age was associated with lower activity levels and lower fat-free mass. After controlling for age there was no longer any association between physical activity and fat-free mass. A few exercise intervention studies showed that elderly subjects compensate for exercise training by a decline in spontaneous physical activity, in contrast to younger subjects. Although no effect of habitual activity level on changes in body composition are observed, training has a positive effect on muscle function. Elderly subjects with relatively high levels of physical activity are not different from those with low activity levels, as far as fat-free mass and fat mass are concerned. However, training might delay the age-induced impairment of personal mobility associated with a reduction in physical activity.

INCREASING age is associated with declining physical activity and with changes in a number of physiological parameters. While the decline in physiological functioning is most likely inevitable, it is far more pronounced in some individuals than in others. As a result, there is a great deal of individual variation in function and quality of life within the elderly population. The basic question is whether physical activity and exercise training have an impact on the physiology of the aging process. However, the problem in most studies is that the effects of age always have to be inferred from comparisons across individuals of different ages (cross-sectional design) or by comparing data from the same individual across two points in time (longitudinal design). Neither approach provides clear-cut data regarding cause and effect, and there are practical limitations regarding more conclusive experimental designs. It is very difficult to manipulate and monitor physical activity levels of a subject, particularly in the long term, while measuring the relevant physiological parameters of aging. This review will examine the observed links between physical activity, energy expenditure, and body composition in aging from a physiological perspective. The present focus will be on activity-associated energy expenditure and on fat-free mass as the relevant physiological parameters for the aging process. The data selected for review are largely derived from studies using doubly labeled water procedures. This technique, utilizing water labeled with the stable isotopes ^{18}O and ^{2}H, has been applied to the assessment of total energy expenditure in humans under daily living conditions since the early 1980s.

The key topics to be addressed are physical activity and age; physical activity and exercise training; physical activity and body composition; and interrelationships between physical activity, body composition, and basal metabolic rate. Thus, we addressed the following questions: what is the effect of age on habitual physical activity? What is the effect of exercise training on habitual activity across age ranges? Are age-related changes in body composition delayed in subjects with a relatively high habitual activity level?

Methodology

Techniques for the assessment of physical activity can be grouped into five general categories: behavioral observation, questionnaires (including activity diaries, recall questionnaires, and interviews), physiological markers such as heart rate, calorimetry, and motion sensors. Validated techniques of estimating habitual physical activity are needed to study the relationship between physical activity and age. However, the greatest obstacle to validating observational or field methods of assessing physical activity in humans has been the lack of an adequate "gold standard" criterion to which such methodologies can be compared. Correlations between different field methods provide a measure of relative validity; however, since all methods are subject to error, it is impossible to obtain absolute validity measures (1). Recently, calorimetry, and more specifically, the doubly labeled water method, has become such a "gold standard" for the validation of existing methods of assessing physical activity outside the laboratory. Unfortunately, only a few validated methods are available and even fewer studies have addressed aging-related issues. This review will therefore focus on data obtained using the doubly labeled water technique itself.

Total energy expenditure (TEE) can be divided into three components: resting or basal metabolic rate (RMR and BMR), diet-induced energy expenditure, and activity-induced energy expenditure (AEE). To compare activity levels across individuals, total energy expenditure obtained using doubly labeled water needs to be adjusted for body size. Published studies used several options, generally dividing TEE or AEE by weight or weight to an exponent between 0.5 and

1.0. The rationale of the latter is that physical activity is a mix of weight-dependent and non-weight-dependent activities. Unfortunately, there is no generalizable coefficient for adjusting TEE or AEE (2). A frequently used method to quantify physical activity is by expressing TEE as a multiple of RMR or BMR (PAL [physical activity level] = TEE/BMR). This method assumes that the variation in TEE is due to body size and physical activity. Adjusting TEE for RMR or BMR implies the use of metabolic body mass as the denominator or body mass to the exponent 0.66 to 0.75. RMR or BMR is generally measured under standard conditions, just after rising, at least 10 hours after the last meal, at rest in the thermoneutral zone.

In the studies reviewed, body composition was assessed with hydrodensitometry or with isotope dilution. To allow comparisons of body composition between subjects, fat mass (FM) and fat-free mass (FFM) were expressed as an index: FMI and FFMI, respectively, where FMI = FM/height^2 and FFMI = FFM/height^2 (FM and FFM in kilograms and height in meters). In this way we corrected for differences in height, in analogy with the body mass index (BMI): BMI = FFMI + FMI.

Results

Physical Activity Declines With Age

Black and colleagues (3) reviewed studies that examined the effects of age, sex, height, and body weight on free-living energy expenditure assessed using doubly labeled water. Included were studies on a total of 574 subjects from developed countries, published from 1985 up until the middle of 1994. This number included 163 subjects under 18 years, 319 subjects aged 18 to 64 years, and 92 subjects aged ≥65 years. Distributions of physical activity levels and total energy expenditure values were shifted downward for subjects aged ≥65 years in comparison to the 1 to 64 years of age group. Multiple regression analysis showed that the effects of age were more pronounced for AEE (AEE = TEE − BMR) than for basal metabolic rate, suggesting that older people have lower physical activity levels.

Figure 1 shows energy expenditure values under daily living conditions and body composition data, as measured in the same Caucasian subjects tested in our laboratory between 1983 and 1998. Excluded were subjects younger than 20 years, those who followed a specific diet for medical reasons, weight loss, or weight gain, subjects who were very physically active (including athletes), women who were pregnant or lactating, and those with disease. Subjects with BMI values of less than 17 and more than 40 were also excluded. The 316 subjects, 136 women and 180 men, were split into four age groups: 20 to 34 years (53 women and 52 men); 35 to 49 years (32 women and 61 men); 60 to 74 years (21 women and 34 men); and 75+ years (30 women and 33 men). Diet-induced energy expenditure was calculated as 10 percent of total energy expenditure. Total energy expenditure in women was lower in the 60- to 74-year group (10.1 ± 1.9 MJ/d) than in the younger groups (12.4 ± 2.1 MJ/d; $p < .001$). Total energy expenditure in men was also lower in the older group (10.9 ± 1.9 MJ/d) as compared to the younger groups (13.7 ± 2.2 MJ/d; $p < .0001$).

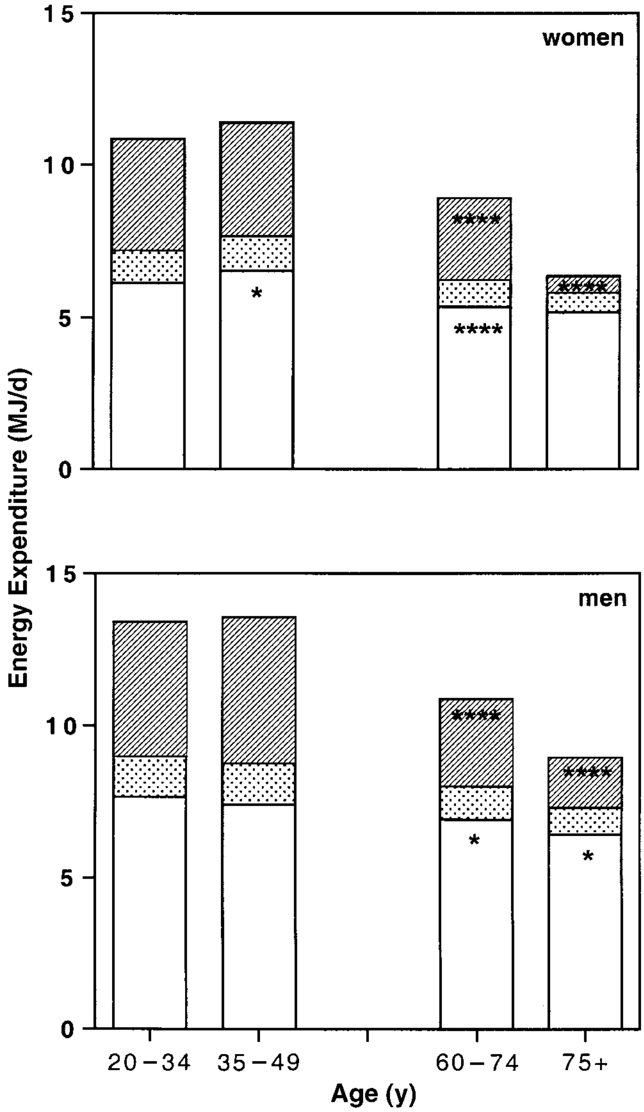

Figure 1. Total energy expenditure and the components of energy expenditure in four age groups; see text for subject selection. □: basal metabolic rate; ▒: diet-induced energy expenditure; ▨: activity-induced energy expenditure. *$p < .05$; ****$p < .0001$, for the difference with the same component in the next younger (left) age group.

Total energy expenditure in the 75+ group was even lower in women (7.6 ± 2.0 MJ/d; $p < .001$) and in men (8.9 ± 1.8 MJ/d; $p < .0001$) than in the 60- to 74-year group. The two oldest groups had the lowest basal metabolic rate. However, it was the age-associated decline in AEE that accounted for most of the decline in TEE. Estimated physical activity levels were 1.76 ± 0.20 for 20- to 34-year-olds, 1.79 ± 0.25 for 35- to 49-year-olds (no difference), 1.62 ± 0.26 for 60- to 74-year-olds (lower, $p < .001$), and 1.31 ± 0.24 for >75-year-olds (lower, $p < .0001$).

Effects of Exercise Training

A few exercise intervention studies measured the effect of imposed exercise training on total energy expenditure and its components. Westerterp (4) reviewed the five published studies, one conducted in subjects under 18 years, three conducted in subjects aged 24 to 41 years, and one in older subjects aged 56 to 78 years. The principal questions of interest were whether exercise intervention has an impact on "spontaneous" physical activity; whether the size of the change in AEE is equivalent to the training load; and whether exercise intervention has an impact on resting or basal metabolic rate.

Imposed exercise training did not influence spontaneous activity in younger subjects so that their total physical activity levels increased. In contrast, elderly subjects compensated for exercise training by a decline in spontaneous physical activity, so that the overall physical activity levels remained unchanged. Exercise training did not influence resting metabolic rate in sedentary subjects when body weight was maintained. Finally, an exercise-induced increase in TEE was about twice the training load—again, except in the elderly subjects where TEE remained the same. The observation that exercise training has no effect on total energy expenditure in elderly subjects is consistent with data from two recent studies in which activity-induced energy expenditure was calculated from activity recordings (5) or assessed with a tri-axial accelerometer (6). However, not all studies have been so consistent. On the other hand, Bunyard and colleagues (7) showed that the energy requirements of healthy and sedentary, middle-aged men are modifiable by regular physical activity. These authors successfully increased energy requirements for weight maintenance by 5% to 7% after 6 months of aerobic exercise. Additionally, they showed a reduction of energy requirements for weight maintenance of more than 15% in middle-aged athletes after 3 months of deconditioning.

Physical Activity and Body Composition

Older people lose fat-free mass. One question is whether the loss of fat-free mass can be prevented or delayed by a program of physical activity. Data showing fat-free mass and body fat of subjects tested in our laboratory are shown in Figure 2. Clearly, older subjects had significantly less fat-free mass, whereas the amount of body fat either increased or remained the same. The loss of fat-free mass with age is mainly a reflection of the loss of muscle mass. Regular physical activity might therefore delay the age-associated decline in FFM. However, longitudinal data on changes in habitual physical activity and body composition are not yet available. Instead, we have conducted a cross-sectional analysis to examine the effects of age, habitual activity level, and body fat on fat-free mass in subjects aged 60 years and over. A similar study had been performed on subjects in the 20- to 50-year-old range (8). The study was based on the previously described subject population shown in Figure 1. They included 21 women and 34 men aged 60 to 74 years and 30 women and 33 men aged 75+ years.

Increasing age was associated with lower physical activity levels (Table 1). This relationship held for both women ($r^2 = .51$, $p < .0001$) and for men ($r^2 = .21$, $p < .0001$). Fat-free mass index was positively associated with physical activity level and negatively associated with age. In contrast, body fat was not associated with either age or with physical activity level. After controlling for age, there was

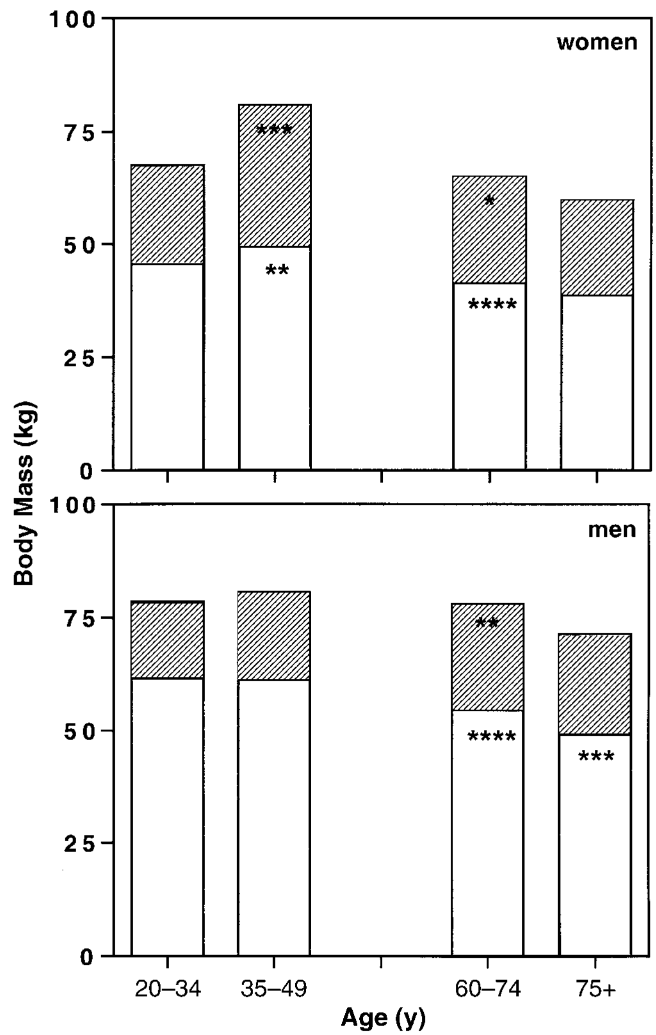

Figure 2. Body mass and the components in four age groups; see text for subject selection. □: fat-free mass; ▨: fat mass. *$p < .01$; ***$p < .001$; ****$p < .0001$, for the difference with the same component in the next younger (left) age group.

no longer any association between physical activity and fat-free mass, either for women or for men. In other words, in this cross-sectional study, increased activity was not associated with greater fat-free mass.

Physical Activity, Body Composition, and Basal Metabolic Rate

Basal metabolic rate also shows a steady decline with age in subjects aged 60 years and over (Figure 1). Changes in basal metabolic rate with age can be largely explained by a reduction of fat-free mass; however, after adjustment for FFM, basal metabolic rate is also found to be slightly lower in the elderly subjects (9,10). This drop in basal metabolic rate, observed in elderly as compared with younger subjects, could be a function of declining physical activity levels. Elderly subjects, with mean physical activity levels below those of younger subjects, would have a lower

Table 1. Explained Variance (%) of Fat-Free Mass Index (FFMI) on Fat Mass Index (FMI), Physical Activity Level (PAL) and Age

Variable	FMI	PAL	Age
Women (n = 51)			
FFMI	20***	13*	16**
FMI		0	5(NS)
PAL			51****
Men (n = 63)			
FFMI	6*	11**	18***
FMI		0	0
PAL			21****

*p < .05; **p < .01; ***p < .001; ****p < .0001.

metabolic activity per unit of fat-free mass. Figure 3 shows basal metabolic rate plotted as a function of fat-free mass in subjects from the Maastricht database. The group has been split into younger subjects in the 20- to 49-year-old range and older subjects in the 60+-year-old range (lower panel). The regression equation was not different for the two groups:

$$20\text{–}49\text{ y: BMR (MJ/d)} = 0.090\text{ FFM (kg)} + 1.98\ (r^2 = .66)$$

$$60+\text{ y: BMR (MJ/d)} = 0.100\text{ FFM (kg)} + 1.38\ (r^2 = .71).$$

Multiple regression analysis, using basal metabolic rate as the dependent variable, showed that physical activity had a negative effect on BMR. In other words, subjects with higher physical activity levels had lower BMR values, once adjustment for fat-free mass had been made (see Discussion):

$$20\text{–}49\text{ y: BMR (MJ/d)} = 0.093\text{ FFM (kg)} - 1.053\text{ PAL} + 3.71\ (r^2 = .71)$$

$$60+\text{ y: BMR (MJ/d)} = 0.107\text{ FFM (kg)} - 0.769\text{ PAL} + 2.15\ (r^2 = .76).$$

Discussion

The decline in total energy expenditure with age is mainly a reflection of a decline in physical activity, as demonstrated using the doubly labeled water technique. Increasing physical activity through exercise training has the potential to develop and maintain strength, flexibility, and cardiovascular fitness. Exercise may delay the age-associated change in body composition, that is, the loss of fat-free mass and the gain in fat mass or body fat. However, data from long-term exercise intervention studies, based on accurate measures of activity-induced energy expenditure, are not yet available. Any discussion of the potential of exercise must still be based on cross-sectional data, even though TEE and BMR are now assessed using the doubly labeled water technique.

Two large databases, that of Black and colleagues (3) and the one presented in the current article (Maastricht data), had a similar number of subjects in higher-age groups, 92 subjects ≥65 years and 118 subjects ≥60 years, respectively. The two data sets were nonoverlapping and only one study in elderly subjects, with 11 women and 19 men, was included in both databases. Analysis of the two data sets led to similar conclusions. A significant drop in AEE can largely explain the decline in total energy expenditure with age. The drop of 37% and 35% in TEE for women and men, respectively, between the ages of 20 and 34 years and 75+ years, was mainly a consequence of a substantial reduction in AEE, as indicated in Figure 1. While basal metabolic rate is the main component of TEE in young adults, the relative contribution of BMR to TEE in elderly people is even higher, because of the lower relative contribution of AEE.

Mean physical activity levels, as reported by Black and colleagues (3), ranged from 1.64 to 1.85 for women and men in the younger-age groups, 1.61 to 1.62 for 65- to 74-

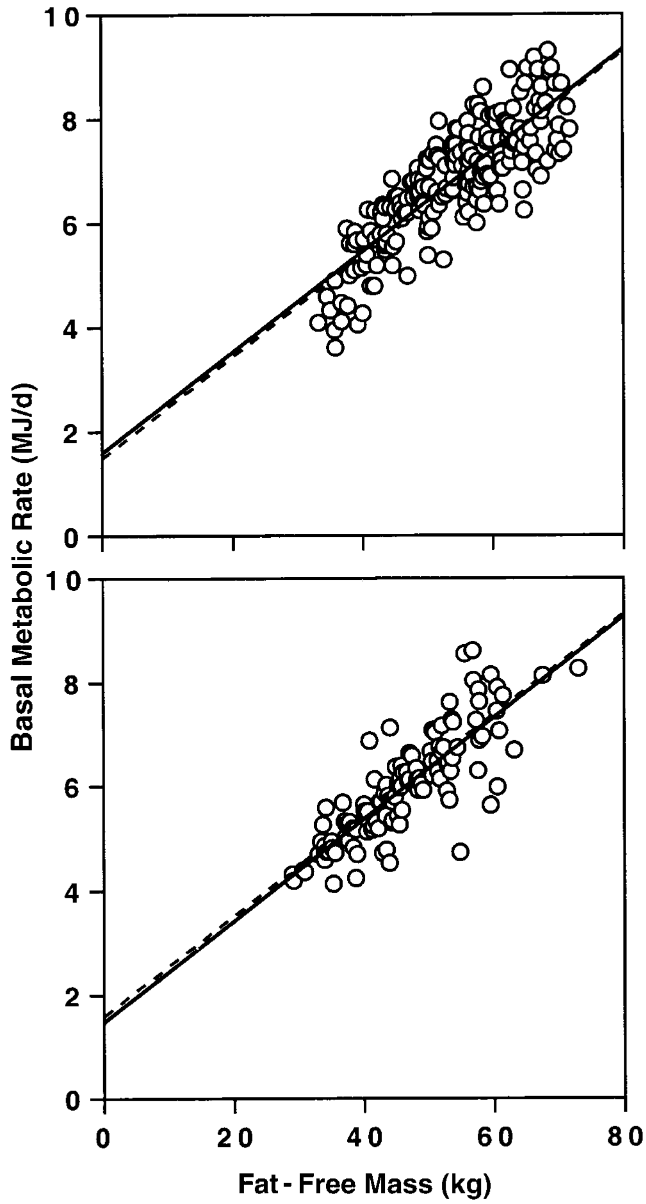

Figure 3. Basal metabolic rate plotted as a function of fat-free mass with the calculated regression line in subjects 20 to 49 years (upper panel) and subjects 60+ years (lower panel). The dotted line is the regression line of the other group.

year-old subjects, and 1.48 to 1.54 for 75+-year subjects. Physical activity levels for the Maastricht database were similar, except that PAL values for subjects aged 75+ years were 1.31 ± 0.24. The latter could be a reflection of a difference in subject sample between the two data sets, given that the Maastricht data set included more subjects living in homes. The FAO/WHO/UNU (11) estimated the PAL of a 75-year-old healthy retired man at 1.51, a figure well in line with the presented values. The lower value of 1.31 ± 0.24 for subjects aged 75+ years in the Maastricht database suggests that many of the oldest subjects were at an absolute minimum of physical activity, close to permanent bed rest. On the other hand, all age groups had a similar range of physical activity and consequently there were subjects with a PAL well above the group mean even among the oldest subjects.

One hypothesis has been that maintaining high levels of physical activity with increasing age may delay the loss of muscle mass or FFM. Conversely, subjects with a higher FFM might find it easier to maintain a higher level of physical activity with increasing age. Thus, in a cross-sectional sample, the more physically active subjects at a given age would also be expected to have a higher FFMI. Surprisingly then, after controlling for age, there was no association between physical activity and fat-free mass. Apparently, there was no relation between habitual activity level and FFMI, and elevated activity levels were not associated with a delayed loss of fat-free mass. However, the effect of physical activity on fat-free mass can be obscured by the relationship between physical activity and body fat. Fat mass and fat-free mass are associated variables, as many large individuals are better able to support and carry the extra fat. Table 1 shows the significant positive association between FMI and FFMI that holds for both women and men.

Higher physical activity levels in subjects over 60 years was not associated with a lower body fat, as had been shown previously for men aged 20 to 50 years (8). We have to conclude that elderly subjects with relatively high levels of physical activity are not different from those with low activity levels, as far as fat-free mass and fat mass are concerned. In other words, body size and body fatness appear unrelated to physical activity levels in subjects over the age of 60.

The question is whether specific exercise training can help. Exercise training is the indicated method to increase and maintain muscle mass and muscle strength. All five training studies reviewed by Westerterp (4) reported no significant changes in body weight or only small changes. However, all five studies showed a significant increase in FFM with exercise training and some showed a decrease in FM. Even in the study on elderly people (12), where total energy expenditure remained the same, the subjects gained 0.85 ± 1.01 kg of FFM over the 8-week training interval. However, that increase in FFM was explained by an increase in total body water, whereas exercise training had no effect on the mass of mineral or protein in the body. The exercise training intervention in younger subjects resulted in "real" increases in FFM, probably through an increase in muscle mass.

A recent review on the effect of exercise training in individuals over the age of 55 concluded that the effect of exercise on body composition was a function of the exercise mode (13). In the selected intervention studies with a duration of at least 2 months, aerobic exercise reduced fat mass by 0.4 to 3.2 kg, while resistance exercise reduced fat mass by 0.9 to 2.7 kg. Resistance training also increased fat-free mass by 1.1 to 2.1 kg, while aerobic training had no effect on FFM. While the loss of fat mass in response to aerobic training was related to the duration of the training, the effects of resistance training on body composition were not related to the duration of the training. The question remains whether elderly subjects can incorporate sufficient resistance exercise in the daily routine to delay significantly the progressive loss of muscle mass with aging.

One interesting phenomenon is the impact of exercise training on TEE and AEE in elderly subjects. Measuring both TEE and AEE using doubly labeled water, Goran and Poehlman (12), in a well-controlled study, showed that exercise training did not result in an increase in TEE. The imposed exercise training activity was compensated for by a corresponding decline in "spontaneous" activity. These authors speculated that the level of exercise, 3 hours per week at 85% of $\dot{V}O_2$-max, was too vigorous and thus fatigued the elderly subjects during the remainder of the day. However, Meijer and colleagues (6) showed the same compensatory effect of exercise training on spontaneous physical activity in elderly subjects who underwent a training program of only moderate intensity.

This observed absence of an effect of exercise training on TEE in elderly subjects is contrary to the findings in younger subjects (4). Other than for the elderly subjects, the magnitude of the change in AEE, on average, was twice the energy cost of the training intervention. The exercise intervention in all past studies with younger subjects did not affect spontaneous physical activity so that total energy expenditure showed a net increase. This did not happen in elderly subjects. The proposed explanation—that exercise fatigues elderly subjects and thus reduces spontaneous activity afterward, resulting in the compensatory response even with moderate intensity training—seems too simplistic. With a tri-axial accelerometer for movement registration, Meijer and colleagues (6) showed that elderly subjects anticipate the advent of exercise training by lowering their physical activity even before the exercise training sessions.

The earlier reported reduction in BMR in elderly subjects, after adjustment for fat-free mass, was not confirmed by the present data (Figure 3). One of the reasons might be that the small difference did not show up in a combination of data from different studies. Earlier reports were based on comparisons between age groups within the same study. More surprisingly, physical activity seemed to have a negative effect on fat-free mass, after adjusting for BMR in both age groups. Clearly, we must realize that this might result from the fact that BMR was included in one of the "independent" variables of the multiple regression analysis. Physical activity calculated as the ratio of TEE/BMR is bound to be lower in subjects of the same size with the same AEE and a higher basal metabolic rate. Unfortunately, there are as yet hardly any published data on BMR and FFM in subjects where physical activity was assessed with an alternative activity measure that was validated with doubly labeled water.

Exercise studies comparing fat-free mass and basal metabolic rate before and after the training intervention do not suggest that higher activity levels lead to higher FFM values after adjusting for BMR (4). Only endurance athletes with a TEE of >20 MJ/d had an increased basal metabolic rate. Sedentary subjects showed the opposite during a 40-week training intervention: resting metabolic rate decreased from 6.46 ± 0.62 to 6.32 ± 0.61 MJ/d ($p < .01$), whereas fat-free mass increased by 5%. The change in resting metabolic rate was related to the change in body mass. Subjects who lost weight because of an exercise-induced loss of fat mass showed a decrease in resting metabolic rate, despite an increase in FFM.

Although no effect of habitual activity level on changes in body composition was observed, training has a considerable impact on skeletal muscle (14). Coggan and colleagues (15) showed that training improved maximal oxygen consumption, muscle-fiber-type composition, capillary density, and oxidative capacity of aged skeletal muscle. Furthermore, these adaptations to a training program were similar to changes observed in young adults. However, it has to be mentioned that training cannot completely prevent age-related changes in these variables (16). The adaptations that are evident with aging can only be minimized with training (Table 2). Therefore, a high habitual activity level appears to be the critical factor in maintaining the structure and function of skeletal muscle and, indirectly, the quality of life.

Despite the absence of an effect of the habitual activity level on body composition and of exercise training on total energy expenditure in elderly people, there are many beneficial effects of increased physical activity on the physiology of elderly subjects. Important aspects are aerobic capacity and strength as determinants of independent living at old age. Among aspects of physical performance that are positively influenced by an increased level of physical activity are endurance, flexibility, range of motion, and balance control (17). A portion of the lost reserve that accompanies aging might be due to disuse and deconditioning and can be reversed with training. Training might delay the age-induced impairment of personal mobility associated with a reduction in physical activity, eventually reflected in a reduction of the physiological body functions such as coordination, circulation and ventilation, and a further loss of muscle mass and bone mass. A change in nutrition and activity lifestyle has been associated with all-cause mortality rates. Taking up a physically active way of life has a favorable impact on longevity (18).

Table 2. Summary of Muscle Adaptations to Aging and Training in Elderly Subjects

Variable	Aging	Training
Maximal Oxygen Consumption	Decrease	Increase
Capillary Density	Decrease	Increase
Fiber-Type Composition		
% Type I	Increase	No change
% Type IIa	No change	Increase
% Type IIb	Decrease	No change
Oxidative Capacity		
Lactate dehydrogenase	Decrease	Increase
Citrate synthase	Decrease	Increase
Succinate dehydrogenase	Decrease	Increase

Acknowledgments

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