



# Exercise, energy balance and body composition

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Received: 10 April 2018 / Accepted: 10 April 2018

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## Abstract

Activity-induced energy expenditure, as determined by the activity pattern including exercise, is the most variable component of daily energy expenditure. Here, the focus is on effects of exercise training on energy balance and body composition in subjects with a sedentary or light-active lifestyle. Then, exercise training induces an energy imbalance consistently lower than prescribed energy expenditure from exercise. Additionally, individual responses are highly variable and decrease in time. Combining the results from 23 exercise training studies in normal-weight, overweight, and obese subjects, varying in duration from 2 to 64 weeks, showed an average initial energy imbalance of about 2 MJ/day with an exponential decline to nearly zero after about 1 year. A compensatory increase in energy intake is the most likely explanation for the lower than expected effect of exercise on energy balance. Overall, exercise training results in a healthier body composition as reflected by a reduction of body fat, especially in overweight and obese subjects, with little or no long-term effect on body weight.

## Basics in clinical nutrition

Activity-induced energy expenditure is the most variable component of daily energy expenditure (DEE), as determined by the activity pattern including exercise. Variation in energy expenditure determines, with energy intake, energy balance, and eventually body composition, when energy imbalance is covered by storage or mobilization of body fat. Additionally, consistent changes in physical activity through immobilization or exercise training affect body composition by changes in muscle mass. Thus, elite athletes like participants in Olympic events have a lower body fat percentage than the average value for similar aged subjects of the general population [1]. Body mass index in athletes is a better proxy for muscle mass than for adiposity [2].

The elite athlete is an example of maximum sustained energy expenditure while maintaining energy balance [3]. Endurance athletes, like Tour de France participants consume energy-dense carbohydrate-rich foods and liquid formulas in order to compete at top level [4]. In the general

population, physical activity level (PAL), calculated as DEE divided by resting energy expenditure (REE,  $PAL = DEE/REE$ ) reaches a maximum value of 2.00–2.40 as shown by well-controlled exercise intervention studies [5]. FAO/WHO/United Nations University classified PAL into three categories: 1.40–1.69 for a sedentary or light-active lifestyle; 1.70–1.99 for active or moderately active lifestyles; and 2.00–2.40 for a vigorously active lifestyle [6]. Here, the focus is on effects of exercise on energy balance and body composition in subjects with light to moderately active lifestyle, that is, an initial PAL around the population average of 1.75.

Studies of exercise affecting energy balance and body composition necessarily involve observations over weeks rather than days. In military cadets with day-to-day changes in exercise expenditure, energy balance varied from day-to-day as well, but energy intake correlated with expenditure over weeks, and even better over longer intervals [7]. Additionally, energy imbalances have to be large or to be sustained over longer time to result in detectable changes in body composition. A change in fat mass that can be measured with a three-compartment model for body composition in an individual subject has to be larger than 1.5 kg, equivalent to about 60 MJ [8]. Exercise energy expenditure of a normal-weight adult with a PAL of 1.75 is 3–4 MJ per day and 20–30 MJ per week [6]. Thus, the minimum intervention interval of exercise studies included in the analysis was 2 weeks.

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Thomas et al. [9] evaluated effects of exercise on energy balance, based on data published until 2012. The analysis covered 15 studies with a total of 657 subjects, 518 women, and 139 men, age 21–69 years, body mass index 20–35 kg/m<sup>2</sup>, and intervention interval 3–64 weeks. In two three-week studies, under fully controlled confined conditions, an exercise-induced negative energy balance was equivalent to the calculated change in body energy stores. For the majority of studies, being longer and under less controlled conditions, the achieved energy imbalance was consistently lower than prescribed energy expenditure from exercise. One explanation is compliance with an exercise program without compensating for an exercise-induced increase in energy expenditure by increasing energy intake. Intake compensation was suggested to be a function of baseline body composition. Studies under confined conditions suggested a compensatory increase in intake to an exercise-induced increase in expenditure might not begin until body energy stores are depleted [10, 11].

## Present research activities

In normal-weight subjects, exercise training had little or no effect on body weight [12]. A long-term intervention study, training sedentary women and men with a body mass index between 19 and 26 kg/m<sup>2</sup> to run a half-marathon after 44 weeks, showed no change in body weight until the final observation at 40 weeks. Then, men showed a median weight loss of 1 kg and similar losses in women were not significant. However, there were pronounced changes in body composition, with a loss in fat mass nearly fully compensated by an increase in fat-free mass. In men, the loss in fat mass was positively correlated with initial percentage body fat. Thus, exercise training resulted in a healthier body composition, especially for subjects with larger body fat stores.

In overweight and obese subjects, exercise training resulted in effects on body weight and body composition with large inter-individual variation. Sedentary overweight and obese women and men, subjected to a 12-week intervention with five supervised exercise sessions per week, showed individual changes ranging from –14.7 to +1.7 kg for body weight and from –9.5 to +2.6 kg for body fat [13]. Mean weight loss of  $3.7 \pm 3.6$  kg was comparable to mean fat loss of  $3.7 \pm 2.6$  kg. The energy content of body fat loss was close to the programmed exercise expenditure of 2.1 MJ (500 kcal) per session, resulting in  $12 \times 5 \times 2.1 = 126$  MJ for the total intervention, equivalent to 3.2 kg fat. A 10-month exercise intervention in overweight and obese women and men, also with five supervised exercise sessions per week, resulted in similar inter-individual variation [14]. A group exercising at 1.7 MJ (400 kcal) per session lost 3.9

$\pm 4.9$  kg and a group exercising at 2.5 MJ (600 kcal) per session lost  $5.2 \pm 5.9$  kg body weight and again, mean values for fat loss were comparable to weight loss. However, fat loss over 10 months was not much larger than fat loss over the similar 3-month intervention of the earlier study described above. Thus, individual responses of exercise training on energy balance and body composition in overweight and obese subjects are highly variable and reach a plateau in time.

So far, an evidence-based explanation for the large variation in response of exercise training on energy balance and body composition is lacking. Potential explanations are an effect of exercise training on energy intake, non-exercise physical activity, and/or REE. Energy intake measurement for the assessment of energy balance, as based on self-report, is not sufficiently accurate [15]. In normal-weight subjects training to run a half-marathon after 44 weeks [16], non-REE increased 2.5 MJ per day while self-reported intake remained unchanged, suggesting a cumulative energy imbalance equivalent to 20 kg fat, five to ten times more than the observed body fat loss [5, 12]. Reviews on behavioral changes in response to exercise training showed no clinically significant changes in non-exercise physical activity during the initiation and adaptation to exercise [17–19]. A review of studies on exercise effects on energy balance in sedentary subjects could only conclude that REE does not change as long as body weight is maintained [9].

## Need of future research

Knowledge about mechanisms behind variation in responses of exercise training on energy balance and body composition is useful to optimize exercise for prevention and treatment of overweight and obesity. The largest part of the response variability is ascribed to exercise-induced changes in energy intake [20]. An answer might come from a large randomized controlled exercise study in sedentary overweight and obese subjects, completed in 2015 (ClinicalTrials.gov ID: NCT01264406) [21]. In this study, energy intake will be derived from energy expenditure measured with doubly labeled water, adjusted for changes in body composition. Additional questions to be answered are: what limits exercise-induced fat loss; why does an exercise-induced change in body composition plateau in time; and is exercise intensity and exercise volume critical to reduce fat mass.

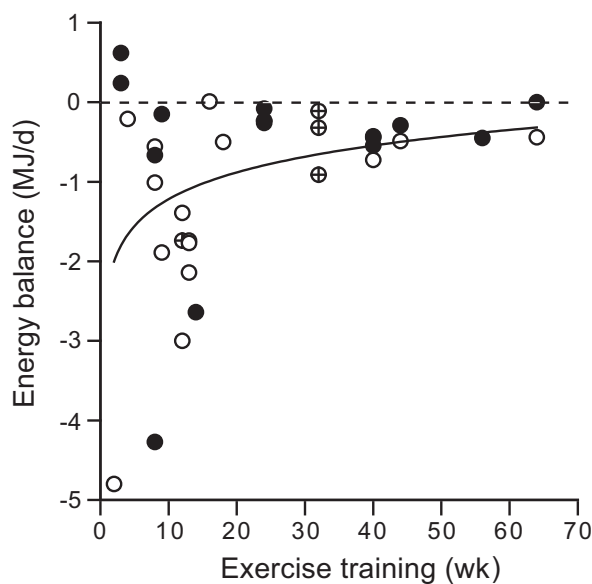
Exercise-induced fat loss is limited by the maximum sustained PAL. The doubly labeled water assessed PAL of overweight subjects and obese is similar to the PAL of normal-weight subjects with a mean value around 1.75 [5]. Activity-induced energy expenditure is similar or slightly higher in most obese subjects. Obese subjects can move less

**Table 1** Exercise training studies with intervention length and observed average changes in body weight and body fat

| Reference | Subjects women/men | Exercise                                   | Interval (week) | $\Delta$ Weight (kg)      | $\Delta$ Body fat (kg)                    |
|-----------|--------------------|--|-----------------|---------------------------|---|
| [10]      | 3/0                | Treadmill 2.5 MJ per day                   | 8               | -6.8                      | -6.0                                      |
| [11]      | 5/0                | Treadmill 1.6 and 3.2 MJ per day           | 3               | 0.5 <sup>NS</sup> and 0.1 | 0.3 <sup>NS</sup> and 0.2 <sup>NS</sup>   |
| [33]      | 0/4                | Treadmill 2.1 MJ per day                   | 12              | -5.1                      | -3.3                                      |
| [26]      | 3/3                | Jogging 20 to 60 min per day               | 9               | -0.9                      | -1.8 <sup>NS</sup>                        |
| [34]      | 13/0               | Cycling 1.5 MJ per day                     | 56              | -3.7                      | -4.6                                      |
| [12]      | 11/12              | Jogging 20 to 40 min per day               | 44              | -1.0                      | -3.5                                      |
| [35]      | 0/10               | Cycling 0.9 MJ per day                     | 4               | 0.5 <sup>NS</sup>         | -0.3 <sup>NS</sup>                        |
| [36]      | 5/6                | Cycling 0.6 MJ per day                     | 8               | 0.0                       | -0.9                                      |
| [37]      | 0/14               | Cycling 2.6 MJ per day                     | 13              | -5.0                      | -4.9                                      |
| [38]      | 0/18               | Resistance 0.6 MJ per day                  | 18              | 0.1 <sup>NS</sup>         | -2.0                                      |
| [39]      | 0/16               | Treadmill 2.9 MJ per day                   | 12              | -7.5                      | -6.1                                      |
| [25]      | 25/16              | Treadmill 1.2 MJ per day                   | 64              | -1.7                      | -2.1                                      |
| [40]      | 17/0               | Treadmill 2.1 MJ per day                   | 14              | -5.9                      | -6.7                                      |
| [27]      | 37/46              | Treadmill 0.6 and 1.4 MJ per day           | 32              | -1.1 and -3.5             | -2.0 and -4.9                             |
| [13]      | 25/10              | Treadmill/cycling 1.5 MJ per day           | 12              | -3.7                      | -3.7                                      |
| [41]      | 309/0              | Treadmill/cycling 0.2 and 0.5 MJ per day   | 24              | -1.4 and -2.1             | -0.1 <sup>NS</sup> and -0.7 <sup>NS</sup> |
| [28]      | 52/14              | Treadmill/cycling 0.9 MJ per day           | 32              | -0.6 <sup>ns</sup>        | -0.6                                      |
| [42]      | 0/36               | Jogging/cycling 1.25 and 2.5 MJ per day    | 13              | -3.6 and -2.7             | -4.0 and -3.8                             |
| [14]      | 37/37              | Treadmill 1.2 and 1.8 MJ per day           | 40              | -3.9 and -5.2             | -3.5 and -5.2                             |
| [24]      | 0/6                | Cycling 193 km per day                     | 2               | 0.4 <sup>NS</sup>         | -2.2                                      |
| [43]      | 0/9                | Treadmill/resistance 0.4 to 0.8 MJ per day | 16              | 0.5 <sup>NS</sup>         | -0.1 <sup>NS</sup>                        |
| [44]      | 0/46               | Jogging/cycling 1.5 MJ per day             | 8               | -1.4                      | -1.6                                      |
| [29]      | 41/38              | Jogging/cycling 0.9 MJ per day             | 24              | -1.1                      | -1.1                                      |

for the same amount of energy through the increased cost of moving a larger body mass [22]. High body weight leads to high activity-induced energy expenditure, even when moving less than normal-weight subjects [23]. With exercise training, resulting in an additional energy expenditure of 2–3 MJ per day, the PAL reaches its maximum value of 2.0–2.4. Thus, the maximum exercise-induced fat loss is about 0.5 kg per week.

An exercise-induced negative energy balance decreases in time, as shown by a compilation of data from 23 exercise training studies varying in duration from 2 to 64 weeks (Table 1 and Fig. 1). The shortest study was in men reaching an extremely high PAL value of about four, during a cycling race over 2706 km, resulting in the most negative energy balance of 4.8 MJ per day, without an effect on body weight [24]. Fat loss, to cover the energy deficit, was similar to the exercise-induced gain in fat-free mass. The longest study was in overweight women and men performing 64 weeks supervised walking and biking exercise increasing to 1.2 MJ per day, resulting in a weight loss in men and no weight change in women [25]. Men lost 5.2 kg weight, mainly as fat, and women showed no exercise-induced change in body composition. Most studies, subjecting women and men to the same exercise intervention, report no



**Fig. 1** Energy balance for studies with different duration of exercise training as presented in Table 1. Energy balance is calculated from the change in body composition using the chemical energy equivalents for changes in fat mass (39.5 MJ/kg) and fat-free mass (7.6 MJ/kg) [32]. Closed dots: women; open dots: men; and crossed dots: women and men

or non-significant gender differences for exercise-induced changes in body composition [13, 14, 26–29].

Compensatory changes explain the decrease of an exercise-induced disturbance of energy balance in time [30]. In addition to compensatory changes in energy intake, DEE does not increase linearly with increasing exercise volume. A cross-sectional analysis showed sedentary individuals tend to adapt metabolically to increased physical activity [31]. A longitudinal study showed an exercise-induced increase in activity-induced energy expenditure, to reach a plateau despite a further doubling of the exercise volume [5]. Training increases exercise economy, especially in sedentary untrained subjects.

In conclusion, in sedentary subjects exercise does affect energy balance and body composition. The achieved energy imbalance is generally lower than prescribed energy expenditure from exercise, especially in normal-weight subjects. In overweight and obese subjects, individual responses of exercise training on energy balance and body composition are highly variable, and reach a plateau in time. At a group level, exercise training results in negative energy balance of about 2.0 MJ per day with an exponential decline to 0.5–0.0 MJ per day in studies longer than 1 year. Exercise training effects on REE and non-training activity are negligible. The most likely explanation for a return to energy balance is a compensatory increase in energy intake.

## Compliance with ethical standards

**Conflict of interest** The author declares that they have no conflict of interest.

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