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PERSPECTIVE

Crystal Ball series

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During the MSc project of my study biology, I was introduced to the interaction between energy expenditure and body weight regulation, and this continued to be my main focus in research. My MSc project was a study on growth efficiency in birds. It started with putting up 50 wooden nest boxes in the national park 'De Hoge Veluwe', to measure energy intake, energy expenditure, and growth in nestlings of starlings from hatching to fledging [1]. Subsequently, my PhD project was a laboratory study on adaptations of energy expenditure during starvation, titled: How rats economize—energy loss in starvation [2]. Following postdoc projects were focused on flight energetics in birds, while developing the use of the doubly labelled water method for measurements. After fourteen years in animal work, I switched to Human Energetics.

The methodology for measuring energy expenditure in the laboratory remained indirect calorimetry. Birds, rats, and humans were housed in a respiration chamber to measure oxygen consumption and carbon dioxide production. To measure energy expenditure under free-living conditions, I developed the use of the doubly labelled water method in a project on the energy budget of the House martin [3]. Isotope analyses were performed at the Scottish Universities Research and Reactor Centre at East Kilbride in Scotland. Back in the Netherlands, I used facilities of the Centre for Isotope Research of the University of Groningen in the Netherlands. At Maastricht University, where I switched to human energetics, I started my own facility while frequently exchanging experiences with the other two initiators of the application of the doubly labelled water method in human research: Dr. Dale Schoeller in the USA and Dr. Andy Coward in the UK.

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As an ecologist, the research questions originated from observations in daily life. Obviously, the most variable component of daily energy expenditure is activity induced energy expenditure. Here, observations on activity induced energy expenditure and energy balance are reviewed thus generating new ideas. Studies are grouped under the headings: assessment of physical activity; inter-individual variation in physical activity; exercise training; high altitude; habitual physical activity; and age.

Assessment of physical activity

Assessment of physical activity in daily life is necessary for understanding relations between physical activity and body weight regulation. Methods include self-reports, monitor-based methods like pedometers and accelerometers, and energy expenditure as criterion measure. At present, doubly labelled water validated accelerometers for movement registration are the preferred method [4]. For assessment of activity induced energy expenditure, the monitor should be trunk mounted, as close as possible to the center of gravity of the body [4]. Thus, accelerometer output can explain more than 50% of the variation in activity induced energy expenditure in daily life [4]. Future devices will allow physical activity recognition to improve accelerometer-based estimations of activity induced energy expenditure as compared to activity counts [4].

Combination of accelerometer assessed body movement with doubly labelled water assessed activity induced energy expenditure showed that moderate-intensity activities are the main determinant of the daily physical activity level [5]. Subjects wanting to increase their daily energy expenditure should exchange low-intensity activities such as sitting for moderate-activities such as walking and cycling [5]. Obese subjects move less despite a similar activity induced energy expenditure, which is explained by the increased cost of moving a larger body mass as body fat and a reduction of movement economy [6].

The diversity of daily physical activities and exercise modalities complicate activity recognition, which can be used to improve the estimation of activity induced energy expenditure with accelerometers. Consumer devices for activity assessment, as incorporated in cellphones, watches, and armbands, already lack accuracy by not being trunk-mounted [4].

Inter-individual variation in physical activity and energy balance

Physical activity level (PAL), expressed as daily energy expenditure as a multiple of resting energy expenditure, ranges between a minimum of 1.1 and a maximum of 2.5 in the general population [7]. The minimum of 1.1 is for a subject at rest all day, with an additional energy expenditure of about 10 % for food processing to maintain energy balance. A typical PAL for a subject confined in a respiration chamber was 1.4 ± 0.1 (range 1.3 to 1.6) [8]. At the average PAL value of 1.7–1.8, as observed in free-living subjects, activity induced energy expenditure is one third of daily energy expenditure [7].

The activity level of a subject as measured in a respiration chamber was related to the activity level in daily life [8]. Subjects with a lower PAL under confined conditions were those with a lower PAL in free-living conditions as well, indicating a genetic component. A subsequent comparative study in monozygotic and dizygotic twins confirmed genetic influence explains a large part of the variation in habitual physical activity [9].

Predisposition to an originally physically active lifestyle does not guarantee a permanent decreased risk of a positive energy balance. With increasing age, a physically active lifestyle usually is not maintained. For instance, a longitudinal study, measuring PAL in the same subjects with a time interval of more than 10 years, showed that an initially higher PAL was remarkably decreased, thus predicting a higher fat gain [10]. The fat gain probably reflects an insufficient adaptation of energy intake to a lower energy requirement, resulting from the reduction of activity induced energy expenditure [10].

Exercise training and energy balance

In the following exercise-training project, sedentary subjects were trained to run a half-marathon after 40 weeks [11]. Participants were 30 to 40 year, normal weight, with an initial body fat 25 to 45% for women and 15 to 31% for men. Nine out of 32 subjects withdrew from the study, all with an initial body fat percentage above the group mean for their sex. Body mass changed little despite pronounced changes in body composition. Loss in fat mass was largely compensated by a gain in fat-free mass, as confirmed in a recent review [12]. Exercise training results in a healthier body composition with little or no long-term effect on body weight [11, 12].

Exercise training has the potential to increase the physical activity level. The PAL of the sedentary subjects trained to run a half-marathon increased from 1.6 ± 0.2 to 2.1 ± 0.2 ($p < 0.001$), a value for a vigorously active lifestyle. The PAL value reached was within the range of 2.0–2.4, the maximum for a sustainable lifestyle with maintenance of energy balance and body weight [7].

Surprisingly, in novice runners, PAL reached a plateau value of 2.1 after 8 weeks of training while with double training volume afterwards it did not increase any further [11]. Results suggested a doubling of exercise economy, yet without further explanation [11]. Endurance athletes can reach PAL values twice as high as the PAL ceiling of 2.0–2.4 for a sustainable lifestyle, maintaining energy balance with energy-dense food supplements [7, 13].

High altitude and energy balance

Altitude exposure induces a negative energy balance, especially when energy expenditure is increased by physical activity like climbing. In three studies, we explored the effect of altitude exposure on energy balance: in subjects climbing Mount Everest, Nepal (8,872 m); during a 21-day sojourn on the summit of Mount Sajama, Bolivia (6,542 m); and over 31 days of progressive hypoxia, simulating an altitude of 4500 to 8848 m, in a hypobaric chamber in COMEX, Marseille, France [14–16].

While climbing Mount Everest, energy intake was low and energy expenditure was high [14]. Measured PAL was 2.3 ± 0.3, a value indicating vigorous activity [14]. All subjects were in a negative energy balance (-5.8 ± 1.8 MJ/d) [14]. Staying for 21 days in tents at Mount Sajama, at 6542 m, the PAL was 1.8 ± 0.3, being slightly higher than for subjects with a sedentary lifestyle living at sea level [15]. However, energy balance was still negative (-2.6 ± 1.5 MJ/d), and not attained at high altitude [15].

Staying in a hypobaric chamber, energy expenditure at a simulated altitude of 5000–7000 m was similar to measured energy expenditure staying in tents at Mount Sajama (6542 m) [16]. Again, subjects did not maintain energy balance despite a wide choice of highly palatable food [16, 17]. Meal size decreased with increasing hypoxia, only partly compensated by increased snacking, resulting in a negative energy balance of -3.0 ± 1.2 and -4.0 ± 1.5 MJ/d during days 2–16 at 5000–7000 m and days 17–30 at 7000–8848 m, respectively [17]. Exposure to hypoxia per se appears to decrease appetite and food intake [17]. Thus it seems difficult to maintain energy balance above 5000 m altitude, even at a low level of physical activity [16, 17].

Energy balance and habitual physical activity

Habitual physical activity is a function of energy balance [18]. Food deprivation in rats, inducing a decrease in body mass from 300 g to 200 g, reduced daily energy expenditure from 173 kJ/d to 69 kJ/d [2]. Activity induced energy expenditure showed the largest relative change [2]. A classical experiment on the effect of semi-starvation in normal-weight men had a similar result [19]. Energy intake was reduced to 50% of maintenance requirement for 6 months and body mass went down from an average of 69 to 53 kg [19]. At the end of the 6 months, energy expenditure equaled energy intake [19]. The decrease in AEE was with 58% the largest contributor to the reduction of daily energy expenditure [20]. Subjects showed a pronounced decrease in physical performance [19].

A daily life example of semi-starvation is anorexia nervosa. Subjects with anorexia nervosa seem to have a high level of daily physical activity. In a study in non-hospitalized women with anorexia nervosa, body mass index ranging from 12.5 to 18.3 kg/m^2, PAL was positively related with BMI [21]. Subjects with a BMI $\geq$ 17 kg/m^2 were equally or more physically active compared with control subjects, while subjects with a BMI < 17 kg/m^2 were less active [21]. At a lower BMI, under-eating and a declining physical capacity limited PAL [21].

Restricting energy intake to lose weight, often practiced in overweight and obese subjects, induces a reduction in physical activity [22]. Accelerometer assessed body movement and PAL decreased when consuming a weight-loss diet and returned to baseline levels when energy balance was reached again during weight maintenance [22]. Overfeeding does not affect PAL, only massive overfeeding has a decreasing effect [23]. Subjects participating in a traditional fattening session, representing twice or threefold habitual intake for about two months, showed no change in daily energy expenditure [24]. Here, resting energy expenditure and postprandial energy expenditure increased at the cost of AEE. The estimated decrease in AEE was 59 ± 10 %, as was also reflected in a reduction of accelerometer assessed body movement [24]. In conclusion, optimal performance requires maintenance of energy balance.

Physical activity, energy balance, and age

Activity induced energy expenditure shows a typical change with increasing age. In children, AEE increases as a fraction of daily energy expenditure from 20 % when they start to move around, to reach a value of 30–45 % when they reach adult height and weight [7]. Corresponding PAL increases from 1.4 to 1.7–1.8. In most adults over age 50, AEE and PAL show again a lower value, even below the initial 20% and 1.4, respectively, when they are over age 80 [25].

The increase in PAL in children and adolescents is mainly determined by the increase in active daytime [26]. Younger children have longer sleeping times. The decrease in PAL at advanced age can have many explanations including muscle loss and changes in muscle composition [25]. The lack of a relationship between age-adjusted PAL and fat-free mass, suggests that greater physical activity does not protect against muscle loss at higher age [25].

At advanced age, exercise training does not affect PAL as it does in young adults [7]. For example, older subjects compensate for exercise training by a decline in spontaneous activity, so that PAL remains unchanged [27]. Subjects at higher age experienced a more negative energy balance than younger subjects over a 10-day interval of strenuous hill walking [28]. Older subjects, able to cycle more than 2700 km from Copenhagen to Nordkapp in 14 days, were able to sustain high energy expenditure but did not maintain energy balance as observed in young adults [29, 30].

Concluding comment

Physical activity is rather a function than a determinant of energy balance. The main determinant of energy balance is energy intake.

Compliance with ethical standards

Conflict of interest The author declares that he has no conflict of interest.

References

1. Westerterp KR. The energy budget of the nestling Starling Sturnus vulgaris: a field study. Ardea. 1973;61:127–58.
2. Westerterp KR. How rats economize—energy loss in starvation. Physiol Zool. 1977;50:331–62.
3. Bryant DM, Westerterp KR. The energy budget of the House martin, Delichon urbica. Ardea. 1980;68:91–102.
4. Plasqui G, Bonomi AG, Westerterp KR. Daily physical activity assessment with accelerometers: new insights and validation studies. Obes Rev. 2013;14:451–62.
5. Westerterp KR. Pattern and intensity of physical activity. Nature. 2001;410:539.
6. Ekelund U, Aman J, Yngve A, Renman C, Westerterp K, Sjöström M. Physical activity but not energy expenditure is reduced in obese adolescents: a case-control study. Am J Clin Nutr. 2002;76:935–41.

7. Westerterp KR. Exercise, energy expenditure and energy balance, as measured with doubly labelled water. Proc Nutr Soc. 2018;77:4–10.
8. Westerterp KR, Kester AD. Physical activity in confined conditions as an indicator of free-living physical activity. Obes Res. 2003;11:865–8.
9. Joosen AM, Gielen M, Vlietinck R, Westerterp KR. Genetic analysis of physical activity in twins. Am J Clin Nutr. 2005;82:1253–9.
10. Westerterp KR, Plasqui G. Physically active lifestyle does not decrease the risk of fattening. PLoS ONE. 2009;4:e4745.
11. Westerterp KR, Meijer GA, Janssen EM, Saris WH, Ten Hoor F. Long-term effect of physical activity on energy balance and body composition. Br J Nutr. 1992;68:21–30.
12. Westerterp KR. Exercise, energy balance and body composition. Eur J Clin Nutr. 2018;72:1246–50.
13. Westerterp KR, Saris WH, Van Es M, Ten Hoor F. Use of the doubly labeled water technique in humans during heavy sustained exercise. J Appl Physiol. 1986;61:2162–7.
14. Westerterp KR, Kayser B, Brouns F, Herry JP, Saris WH. Energy expenditure climbing Mt. Everest. J Appl Physiol. 1992;73:1815–9.
15. Westerterp KR, Kayser B, Wouters L, Le Trong JL, Richalet JP. Energy balance at high altitude of 6542 m. J Appl Physiol. 1994;77:862–6.
16. Westerterp KR, Meijer EP, Rubbens M, Robach P, Richalet JP. Operation Everest III: energy and water balance. Eur J Physiol. 2000;439:483–8.
17. Westerterp-Plantenga MS, Westerterp KR, Rubbens M, Verwegen CR, Richalet JP, Gardette B. Appetite at “high altitude” [Operation Everest III (Comex-’97)]: a simulated ascent of Mount Everest. J Appl Physiol. 1999;87:391–9.
18. Westerterp KR. Energy balance in motion. Heidelberg; Springer, 2013.
19. Keys A, Brozek J, Henschel A, Mickelsen O, Taylor HL. The biology of human starvation. Minneapolis; University of Minnesota Press, 1950.
20. Westerterp KR. Daily physical activity as determined by age, body mass and energy balance. Eur J Appl Physiol. 2015;115:1177–84.
21. Bouten CV, Van Marken Lichtenbelt WD, Westerterp KR. Body mass index and daily physical activity in anorexia nervosa. Med Sci Sports Exerc. 1996;28:967–73.
22. Camps SG, Verhoef SP, Westerterp KR. Weight loss-induced reduction in physical activity recovers during weight maintenance. Am J Clin Nutr. 2013;98:917–23.
23. Joosen AM, Westerterp KR. Energy expenditure during overfeeding. Nutr Metab (Lond). 2006;3:25.
24. Pasquet P, Brigant L, Froment A, Koppert GA, Bard D, de Garine I, et al. Massive overfeeding and energy balance in men: the Guru Walla model. Am J Clin Nutr. 1992;56:483–90.
25. Speakman JR, Westerterp KR. Associations between energy demands, physical activity, and body composition in adult humans between 18 and 96 y of age. Am J Clin Nutr. 2010;92:826–34.
26. Hoos MB, Kuipers H, Gerver WJ, Westerterp KR. Physical activity pattern of children assessed by triaxial accelerometry. Eur J Clin Nutr. 2004;58:1425–8.
27. Meijer EP, Westerterp KR, Verstappen FT. The effect of exercise training on total daily physical activity in the elderly. Eur J Appl Physiol. 1999;80:16–21.
28. Ainslie PN, Campbell IT, Frayn KN, Humphreys SM, MacLaren DP, Reilly T, et al. Energy balance, metabolism, hydration, and performance during strenuous hill walking: the effect of age. J Appl Physiol. 2002;93:714–23.
29. Rosenkilde M, Morville T, Andersen PR, Kjaer K, Rasmusen H, Holst JJ, et al. Inability to match energy intake with energy expenditure at sustained near-maximal rates of energy expenditure in older men during a 14-d cycling expedition. Am J Clin Nutr. 2015;102:1498–05.
30. Westerterp KR. Alterations in energy balance with exercise. Am J Clin Nutr. 1998;68(Suppl):970S–4.