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Seasonal variation in body mass, body composition and activity-induced energy expenditure: a long-term study

Klaas R. Westerterp ¹

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Abstract

Background/Objectives Seasonal variation in body mass is a model for the study of body mass regulation. Here a long-term study is presented on body mass, body composition, and activity-induced energy expenditure in a subject with a large seasonal variation in body mass of about 3.0 kg.

Subject/Methods Body mass was assessed daily over >20 consecutive years. Daily assessment of activity-induced energy expenditure was performed over the last 10 years. Body composition was assessed monthly for 1 year in the middle and at the end of the observation interval. Additionally, data were compared with data on body composition, resting energy expenditure, and total daily energy expenditure of the same subject as a participant in published studies.

Results Body mass showed a pronounced seasonal variation, associated with a synchronous variation in physical activity. Body mass peaked in the cold winter months when physical activity reached the lowest annual value and decreased to the lowest value in mid-summer when daily physical activity peaked. The seasonal variation in body mass consisted mainly of body fat. Longitudinally, over the past 8 years of the observation interval, average fat-free mass showed a decrease of 1.0 kg and fat mass increased 0.8 kg.

Conclusions In a subject with a pronounced seasonal variation in physical activity, activity-induced variation in energy requirement was covered by an annual variation in body mass, mainly as fat. Maintenance of activity-induced energy expenditure did not protect against loss of fat-free body mass with advancing age.

Introduction

Seasonal models represent valuable tools for the study of the mechanistic basis of body mass regulation [1]. Evidence comes mainly from small mammals showing seasonal fattening to cope with food shortage and with decrease of ambient temperature. In man, pronounced seasonal variation in body mass was observed in developing countries where food availability changes seasonally [2]. A rural farming community of The Gambia showed an annual pattern of weight change with an amplitude of 1.6 kg. Loss of body mass occurred during the pre-harvest season, when food availability was limited and physical activity was high.

Similar seasonal body mass patterns were observed in a rural Beninese population [3].

Surprisingly, an annual cycle of body mass still exists in countries where people live most of the day in a temperature-controlled environment and have a guaranteed and varied food supply throughout the year. A study in >6000 smart connected weight scale users in different countries showed subjects mostly lose weight during the warmer seasons and typically gain weight in colder seasons, with similar patterns for countries in northern and southern hemisphere [4]. Explanatory factors include climate patterns affecting energy balance through energy intake and energy expenditure.

Energy intake in developed countries does not systematically change throughout the year. A study in 114 young adult Dutch women consuming self-selected diets did not demonstrate seasonal variations in the mean energy intake of the group, despite seasonal fluctuations in body mass [5]. The magnitude of seasonal patterns of diet composition does not seem to affect energy intake [6].

✉ Klaas R. Westerterp
k.westerterp@maastrichtuniversity.nl

¹ NUTRIM, Maastricht University Medical Centre, Maastricht, The Netherlands

Energy expenditure variation potentially includes variation in resting energy expenditure (REE) and activity-induced energy expenditure. There are indications for seasonal variation in REE. Two studies in subjects living in an environment with a seasonal variation in ambient temperature of 15–20 °C showed lower values in summer and higher values in winter with a difference of 4–5% of the mean [7, 8]; one study did not observe any difference [9]. There were no significant differences in fat-free mass, the main determinant of resting metabolic rate, over the year [8, 9]. Additionally, seasonal differences could not be explained by thyroid activity or leptin concentrations [8]. Studies on seasonal variation in physical activity, the determinant of activity-induced energy expenditure, are more numerous. Observations in adults, assessing physical activity with pedometers and accelerometers, generally showed lower activity levels in winter compared to summer [10–14]. Observed values of pedometer measured step counts were 10–15% higher in summer than in winter [11, 12, 14]. Observed summer versus winter differences in accelerometer assessed total daily physical activity were 5–10% of the annual average [10, 13]. An exception is a study in students in Beijing, showing a constant pattern of urban daily life activity, independent of time of year [15]. Three studies measured seasonal variation of doubly labeled water assessed total daily energy expenditure (TDEE) [9, 16, 17]. None of the three studies showed a significant difference in TDEE between summer and winter. In one study, physical activity level (PAL), calculated as TDEE divided by REE, was higher in winter than in summer. However, higher activity-induced energy expenditure in summer was compensated by lower REE and did not affect TDEE [16]. So far, in the developed countries, there is no evidence for seasonal variation in daily energy expenditure despite observed seasonal variation in physical activity. Observed seasonal variation in physical activity possibly was too small.

None of the studies on seasonal variation in energy intake and energy expenditure in the developed countries, with a guaranteed food supply, showed a relation with seasonal variation in body mass. Seasonal body mass variation as presented was <1 kg. Van Staveren et al. [5] observed a mean seasonal amplitude of 0.8 kg in women from a small industrial town in the Netherlands. Ma et al. [6] observed a difference of about 0.5 kg between summer and winter body mass in an ethnic diverse group living in central Massachusetts, USA. Hamilton et al. [12] observed a difference of 0.6 kg between summer and winter body mass, mainly representing body fat, in adults living in different counties in the UK. The mean seasonal weight variation in >6000 smart connected weight scale users as reported by Mehrang et al. [4] was in the same range, with a value 0.4–0.5%, when assuming mean body mass was <100 kg.

Here a study is presented in a subject with a larger seasonal variation in body mass of about 3.0 kg [18]. Data on body mass and body composition were related to activity-induced energy expenditure as assessed over >30 years.

Methods

The subject was a man residing in the Netherlands, height 1.65 m and age 50 years at the start of daily body mass measurements. Body composition was assessed monthly for 1 year in the middle and at the end of the observation interval. Activity-induced energy expenditure was assessed daily, starting in the 11th year of the >20-year observation. Additionally, data are compared with data on body composition, REE and TDEE of the same subject as participant in published studies [19–23]. The Ethics Committee of the Maastricht University Medical Centre approved the procedures of the study.

Body mass was measured daily without clothing, in the morning after emptying the bladder and before food or water intake, on a scale accurate to ± 0.01 kg (Spider 1, Mettler Toledo, Greifensee, Switzerland). Body composition was measured with Deuterium dilution, following the Maastricht protocol [24]. Activity-induced energy expenditure (MJ/day) was measured with a doubly labeled water validated tri-axial accelerometer for movement registration [25]. Data are summarized using mean and standard deviation.

Results

Data on body mass, body composition and energy expenditure of the same subject from earlier publications covered a 30-year age interval (Table 1). None of the parameters showed a clear trend in time. Body mass was 58.6 ± 0.9 kg and fat mass was 6.8 ± 1.4 kg, resulting in a relative fat mass of 12%. REE was 6.2 ± 0.3 MJ/day. REE combined with TDEE resulted in a PAL (PAL = TDEE/REE) value of 1.8

Table 1 Body mass, fat mass, resting energy expenditure (REE), and total daily energy expenditure (TDEE) of a man, height 1.65 m, as published before

Reference	Age (years)	Body mass (kg)	Fat mass (kg)	REE (MJ/day)	TDEE (MJ/day)
19	38	58.0	7.0	6.6	
20	43	57.3	4.9	6.0	11.2
21	47	59.4	6.5		
22	54	59.0	7.1	6.1	18.2
23	68	59.4	8.7	6.0	
Mean		58.6 ± 0.9	6.8 ± 1.4	6.2 ± 0.3	

Fig. 1 Monthly body weight (**a**, kg) from April 1997 to December 2018 and monthly activity energy expenditure (**b**, MJ/day) from October 2008 to December 2018. J denotes January. Closed dots are values from earlier publications; dotted line denotes overall annual average

and 3.0 at the two measuring points. The first value was an observation under normal living conditions; the latter value was obtained during an experiment over 10 consecutive days on the effect of strenuous hill walking on energy balance.

Daily body weight measurements covered 21.8 consecutive years, combined with daily activity energy expenditure (AEE) measurements over the last 10 years of the same interval. Monthly averages of the two parameters were plotted in time (Fig. 1), showing a clear seasonal effect. Lower body mass was observed in summer and higher values in winter. For physical activity, there was the opposite effect, higher AEE in summer and systematically lower values in winter. Longitudinally, annual maximum body mass was similar while annual minimum values showed a downward trend in time. Physical activity showed no clear longitudinal trend over the subsequent years.

The seasonal change in physical activity and body mass coincided with the seasonal change in ambient temperature as supplied by the Royal Dutch Meteorological Institute at a location within 10 km of residence (Fig. 2). The annual amplitude of the monthly ambient temperature, AEE, and body mass was, respectively, 17.6 ± 3.2 °C, 1.5 ± 0.2 MJ/day, and 3.0 ± 0.7 kg. Ambient temperature showed a positive correlation with average AEE in the same month (Fig. 3, Pearson correlation coefficient 0.91, $p < 0.001$). The difference in body mass between subsequent months was negatively correlated with the difference in AEE (Pearson correlation coefficient 0.73, $p < 0.01$). Extrapolating the regression of Δ body mass on Δ AEE, a difference in AEE

of -30 MJ between months corresponded with a body mass difference $+1.1$ kg.

The seasonal change in body mass consisted mainly of fat mass, as derived from monthly body composition measurements over 2 years, the 13th and last year of the 21.8-year observation interval (Fig. 4). Fat-free mass showed a non-significant annual cycle in both years. Fat mass showed a maximal value in winter and a minimal value in summer with a difference of 2.6 kg and 3.2 kg in the 2 years, respectively. Thus the annual cycle in body mass represented mainly an annual cycle of body fat.

Comparing body composition between the corresponding months of the 2 years with an 8-year interval showed a difference. Fat-free mass decreased over 8 years from an annual average value of 52.1 ± 0.7 kg to 51.1 ± 0.8 kg ($p < 0.001$); fat mass increased from 6.5 ± 0.8 kg to 7.3 ± 1.0 kg ($p < 0.01$).

Discussion

The subject of the study showed a pronounced seasonal variation in body mass, inversely associated with a synchronous variation in physical activity. Body mass peaked in the cold winter months when physical activity reached the lowest annual value and gradually decreased to the lowest value in mid-summer when daily physical activity reached the highest value. The seasonal variation in body mass consisted mainly of a change in body fat. Longitudinally, over the past 8 years of the observation interval,

Fig. 2 Annual cycle of ambient temperature (**a**, Celsius), activity energy expenditure (**b**, MJ/day), and body mass (**c**, kg), as measured from October 2008 to December 2018

Fig. 3 Activity energy expenditure as a function of ambient temperature in the same month (left), and difference in body mass between subsequent months plotted against the difference in activity energy expenditure (right), with the linear regression lines

Fig. 4 Annual cycle of fat-free mass (kg, filled bar) and fat mass (kg, open bar), as measured monthly over the 13th (left) and last year of the 21.8-year observation interval (right) with Deuterium dilution

average fat-free mass showed a decrease of 1.0 kg and fat mass increased 0.8 kg.

The physical activity level (TDEE/REE) of the subject, based on an REE value of 6.2 MJ/day (Table 1) and the assumption that diet-induced energy expenditure was 10% of TDEE for a subject consuming a mixed diet [26], ranged between a value of 1.6 in month 1, when AEE was on average 2.9 MJ/day (Fig. 2b), and 1.8 in month 6, when AEE was on average 3.9 MJ/day. Thus, according to the Food and Agriculture Organization/World Health Organization/United Nations University classification, the subject had a light active lifestyle in winter and a moderately active-to-active lifestyle in summer [27].

The body mass index of the subject, with height 1.65 m and average weight 58.7 kg (Fig. 2c), was 21.6 kg/m², a value in the lower part of the range from 20.0 to 24.9 kg/m² for normal-weight subjects. The body fat mass was low as well, with an average value 6.8 kg of 58.6 kg body mass (Table 1) or 11.6%, and an annual average value of 11.1% and 12.5% in 13th and last year of the observation interval, respectively.

The loss of fat-free mass in the latter part of the observation interval is typical for later adulthood [28]. Also, notably men show a decline in skeletal muscle mass, often associated with an age-associated decline in physical activity [29]. However, a cross-sectional analysis of a large sample measurements of physical activity and body composition with doubly labeled water in humans between 18 and 96 years of age suggested that routine physical activity does not protect against loss of fat-free mass in older subjects [30]. The current longitudinal study, showing a decline in fat-free mass in late adulthood despite an unchanged AEE, confirms this.

The relation between the month-to-month change in AEE and body mass suggests that activity-induced change in energy requirement was fully covered by a change in the body energy store. The estimated energy equivalent of the seasonal body mass change of 30/1.1 = 27 MJ/kg (Fig. 3) is close to a predicted value of 25 MJ/kg for a subject with a body mass between 57 and 60 kg and with 12% body fat [31].

The limitation of the study is that observations were restricted to a single subject. The seasonal pattern of physical activity was mainly induced by the growing season, maintaining a 400 m² vegetable garden and 10–20 beehives. Thus the activity pattern was closer to patterns observed in rural communities than the activity pattern of most citizens.

In conclusion, in a subject with a pronounced seasonal variation in physical activity, the activity-induced variation in energy requirement was covered by an annual variation in body mass of 3 kg. Maintenance of activity-induced energy expenditure did not protect against loss of fat-free body mass with advancing age.

Compliance with ethical standards

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

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