Basal metabolic rate as a proxy for overnight energy expenditure: the effect of age

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Recommendations for daily energy requirements use factorial calculations based on BMR. Expressing total energy requirements as a multiple of BMR is based on the assumption that BMR is equal to overnight metabolic rate (OMR). The objective of the present study was to determine if BMR is an appropriate proxy for OMR in children, young adults and elderly. Data are presented of thirty children (11 (SD 2) years), thirty young adults (25 (SD 5) years) and fifty-nine elderly (61 (SD 5) years). OMR was measured in a respiration chamber while sleep was not hindered and BMR was measured directly afterwards with a ventilated hood system under strictly controlled conditions. The mean ratio of OMR:BMR was 0·92 (SD 0·09) for children, which was significantly different from 1·00 ($P < 0.001$), 1·00 (SD 0·07) for young adults and 1·06 (SD 0·09) for elderly which was also different from 1·00 ($P < 0.001$). For adults, BMR is an appropriate measure of OMR. In children, the use of BMR to estimate OMR would introduce an overestimate and for elderly an underestimate.

Energy requirement: Resting energy expenditure: Body composition: Respiration chamber

Recommendations for daily energy requirements (World Health Organization, 2004) use factorial calculations based on BMR. Expressing total energy requirements as a multiple of BMR is based on the assumption that BMR is equal to overnight metabolic rate (OMR). This assumption has been studied previously. In these studies OMR was defined as the period of actual sleeping or as a fixed period during the night when most subjects were in deep sleep. Fontvieille *et al.* (1993) and Zhang *et al.* (2002) corrected for physical activities during the sleeping period and found OMR:BMR ratios of 0·97 and 1·0, respectively. In other studies OMR:BMR ratios of 0·95 (Garby *et al.* 1987; Goldberg *et al.* 1988; Klausen *et al.* 1997) and 1·0 (Treuth *et al.* 1998; Seale & Conway, 1999) were observed. Vaughan *et al.* (1991) found a ratio of sleeping metabolic rate (SMR) to BMR of 0·89 in young and 1·01 in elderly subjects but the definition of SMR is not well described in their study. The data of previous studies suggest that metabolic rate drops significantly below BMR, but the difference between BMR and OMR is small, and becomes negligible when applied to calculate 24 h energy expenditure. Differences are usually explained by body movements in sleep, interrupted sleep by awakenings and toilet visiting. Except for the study of Treuth *et al.* (1998), the studies mentioned earlier did not include any children. Bines & Truby (2004) studied energy expenditure in infants when sleeping and when lying quietly awake. Measured metabolic rate for the sleeping period was only 76 % of the measured metabolic rate during the awake period. In the Bines & Truby (2004) study infants were not fasted but the time from the last feed

to the beginning of the study was recorded. There was no significant difference in the time from the last feed to the measurement of energy expenditure or for the RQ between the asleep and awake studies, suggesting that the difference observed in the sleeping and awake states is due to the level of arousal. Therefore we hypothesized that the difference between BMR and OMR is greater in children than in adults and elderly. If this hypothesis were to be confirmed, use of BMR to estimate energy expenditure at night would introduce an overestimate of daily energy needs in children.

The objective of the present study was to determine if BMR is an appropriate proxy for overnight energy expenditure for children, young adults and elderly. We analysed data from studies in which OMR was measured in a respiration chamber and BMR was measured under strictly controlled standard conditions.

Methods

Subjects

Data from subjects enrolled in three previous studies and from one new study were analysed (Meijer *et al.* 2001; Hoos *et al.* 2004; van Ooijen *et al.* 2004). Subjects were fourteen male children (10 (SD 1) years), sixteen female children (11 (SD 2) years), ten male young adults (28 (SD 7) years), twenty female young adults (24 (SD 4) years), twenty-four male elderly (62 (SD 5) years) and thirty-five female elderly (61 (SD 4) years). The new study consisted of ten children, ten young adults and thirteen elderly. All of them were females.

All subjects were in good health as assessed by medical history. They were weight-stable during the last 6 months (± 3 kg), did not consume special diets or participate in exercise programmes, and none of them were taking medications. All but one of the young women were either users of oral contraceptives or in pre-ovulatory phase at the measurement day.

All participants and the parents of children younger than 18 years provided written informed consent to participate in the studies, which were approved by the Medical Ethical Committee of Maastricht University.

Physical characteristics of the total group of subjects are presented in Table 1.

Energy expenditure

SMR, OMR and lowest SMR (SMR_{min}) were measured during an overnight stay in a respiration chamber. The respiration chamber was a $14 \, m^3$ room furnished with a bed, chair, computer, radio, telephone, intercom, sink and toilet. Subjects entered the chamber at 19.00 hours and left the room at 07.00 hours. They went to bed at their normal bedtime, which was between 20.00 and 00.00 hours and were woken at 07.00 hours. Energy expenditure was calculated from O_2 consumption and CO_2 production according to Weir's formula. OMR was defined as the average metabolic rate measured between 0.00 and 6.00 hours, because in this time-period all the subjects were in bed. SMR was defined as the average metabolic rate during 3 h during the night with most stable energy expenditure. SMR_{min} was defined as the lowest continuous 60 min period recorded during the night. Subjects were asked to consume their normal evening meal at home at about 18.00 hours. The meals were not standardized, so as not to interfere with the subjects' normal feeding behaviour and, thus, energy balance. Because the last meal was at about 18.00 hours, the effect of diet-induced thermogenesis during the night was assumed to be minimal (Segal *et al.* 1990; Reed & Hill, 1996). Subjects were instructed to refrain from intensive exercise the day before their stay in the respiration chamber. Room temperature was held constant at $19 \pm 1°C$.

Using a ventilated hood system (Omnical, Maastricht University, the Netherlands), BMR was measured for 30 min in the supine position under standard conditions of rest, fasting, immobility, thermoneutrality ($22-24°C$) and mental relaxation. After awakening, subjects needed to leave the chamber and walk approximately 10 m to the ventilated hood system. This was on the same floor as the respiration chamber. After 15 min resting, the BMR measurement was started. To eliminate the effects of subject habituation to the testing procedure, the respiratory measurements during the first 10 min were discarded, and the following 20 min were used to calculate BMR. The ratios of OMR:BMR, SMR:BMR and SMR_{min}:BMR were used to represent the differences between the sleeping state and the awake state.

Body composition

Body weight was estimated directly after the BMR measurement. Subjects were weighed in swimming suits before any food consumption and after emptying the bladder, on a digital balance accurate to 0.01 kg (KCC 300; Mettler, Greifensee, Switzerland). Height was measured to the nearest 0.1 cm (Mod. 220; SECA, Hamburg, Germany). Body volume was measured with underwater weighing. Residual lung volume was simultaneously measured using the helium dilution technique. Total body water was measured with ^2H dilution according to the Maastricht protocol (Westerterp *et al.* 1995). Body composition was calculated from body density and total body water using Siri's three-compartment model (Siri, 1993).

Sleep quality

Information on sleep quality, sleep interruptions and toilet visits, both in the respiration chamber and in normal life, was gathered using a questionnaire. This was an in-house designed questionnaire with multiple-choice questions about sleep quality. For example, how long it took to fall asleep, number of awakenings, number of times subjects got out of bed, and the influence of temperature and noise in the respiration chamber.

Physical activity

In a subgroup of thirty-three subjects (ten children, ten adults and thirteen elderly), body movements were registered during three nights before the measurements and the night in the respiration chamber with a tri-axial accelerometer for movement registration (Tracmor; Philips Research, Eindhoven, the Netherlands). The accelerometer was an improved version

Table 1. Physical characteristics of subjects*

	Children (*n* 30)		Adults (*n* 30)		Elderly (*n* 59)	
	Mean	SD	Mean	SD	Mean	SD
Age (years)	11	2	25	5	61	5
Height (m)	1·41	0·16[a,b]	1·73	0·08[c]	1·68	0·09[c]
Weight (kg)	36·3	14·5[a,b]	68·9	13·7[c]	43·6	12·0[c]
BMI (kg/m^2)	17·6	4·2[a,b]	22·9	3·3[b,c]	26·0	3·9[a,c]
Fat mass (kg)	8·3	6·4[a,b]	16·5	6·4[b,c]	24·7	7·0[a,c]
Fat-free mass (kg)	28·0	9·4[a,b]	52·4	10·7[c]	48·8	9·0[c]
Fat (%)	20·8	8·7[b]	23·8	7·0[b]	33·4	7·1[a,c]

* Children: fourteen male, sixteen female; adults: ten male, twenty female; elderly: twenty-four male, thirty-five female.
[a,b,c] Mean values within a row were significantly different from [a] adults, [b] elderly, [c] children; $P < 0.05$.

(same principle, but smaller) of the accelerometer used in previous studies (Bouten *et al.* 1996). It measures accelerations in the anteroposterior, medio-lateral and vertical directions. The dimensions of the accelerometer are $72 \times 27 \times 8$ mm and it weighs 22 g. Subjects wore the accelerometer in a waist belt at the lower back during sleeping hours. The subjects recorded the times when they went to bed and when they got up. The registered accelerations in counts per minute were used as an objective measure for the physical activity level of each subject. During the night, counts per minute is usually stable at a low level. An obvious increase in counts per minute during the night for 4 min or more was judged as a situation in which subjects got up out of their bed.

Statistics

Data are presented as means and standard deviations. ANOVA was used to determine significant differences between the three age groups. On significant outcomes, a Scheffé *post hoc* analysis was used to determine the significant difference. The SPSS program, version 10 (SPSS Inc., Chicago, IL, USA) was used for the statistical analysis.

Results

Subjects

On average children had a lower height, weight, fat mass, fat-free mass and BMI than young adults and elderly. BMI, fat mass and percentage of fat mass were significantly higher in the elderly in comparison with children and young adults. There was no significant difference in weight, fat-free mass and height between elderly and young adults.

Energy expenditure during sleep and basal conditions

The results of energy expenditure for the three groups are summarized in Table 2. Absolute energy expenditure during basal conditions and during the night was lower in children compared to young adults and elderly. There were no significant differences between young adults and the elderly. When adjusted for fat-free mass, BMR was significantly higher in children in comparison with young adults and elderly. In contrast, adjusted OMR, SMR and SMR_{min} were lower in young adults than in children and elderly. There were no significant differences between children and elderly.

Table 2. Results of energy expenditure measurements*

	Children (n 30)		Adults (n 30)		Elderly (n 59)	
	Mean	SD	Mean	SD	Mean	SD
OMR (kJ/h)	206·0[a,b]	43·7	275·3[c]	53·6	283·3[c]	43·9
SMR (kJ/h)	197·5[a,b]	43·4	261·2[c]	42·6	267·2[c]	46·3
SMR_{min} (kJ/h)	183·6[a,b]	44·5	248·9[c]	42·7	249·1[c]	43·9
BMR (kJ/h)	224·9[a,b]	44·6	273·9[c]	41·9	267·6[c]	43·9

OMR, overnight metabolic rate; SMR, sleeping metabolic rate; SMR_{min}, lowest metabolic rate during a continuous 60 min period in the night.
* For details of procedures, see p. 1167.
[a,b,c] Mean values within a row were significantly different from [a]adults, [b]elderly, [c]children $P < 0.05$.

Relations between BMR and sleeping energy expenditure

The ratios of OMR:BMR, SMR:BMR and SMR_{min}:BMR are presented in Fig.1. The ratio of OMR:BMR was 0·92 (SD0·09) for children, which was significantly different from 1·00 ($P < 0.001$), 1·00 (SD 0·07) for adults and 1·06 (SD 0·09) for elderly which was also different from 1·00 ($P < 0.001$). The observed ratio SMR_{min}:BMR was lowest in children (0·82) and highest in elderly (0·93). The ratio SMR:BMR was lowest in children (0·88) and highest in elderly (0·99).

Sleep quality

Elderly appeared to sleep with more interruptions and toilet visits than adults and children. Adults had more awakenings during the night compared with children, but they did not leave the bed more often. Furthermore, most adults and elderly woke up before the wake-up call in the morning, while most children were still sleeping. However, the judgement of the sleep quality in the chamber and in the home situations was the same for the three age groups.

Body movements

The analysis of the accelerometer data showed that one of the ten children got up in the night two times. The other children stayed in bed for the whole night. Two of the ten adults rose in the night only once, while the other adults did not rise during the night.

On the contrary, nine of the thirteen elderly got up for one to four times. The results of the home situation were comparable with the situation in the respiration chamber.
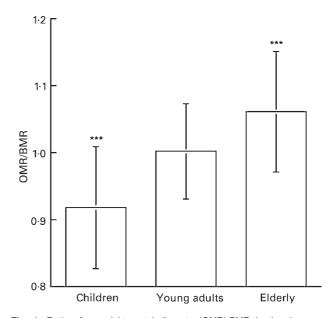

Fig. 1. Ratio of overnight metabolic rate (OMR):BMR in the three age groups. For details of procedures, see p. 1167. Values are means with their standard deviations depicted by vertical bars. Mean values were significantly different from 1: ***$P < 0.001$.

Discussion

The WHO recommendations for daily energy expenditure assume that BMR is equal to OMR. The results of the present study indicate that BMR is an appropriate measure of OMR for adults. The present result is similar to the results of other studies (Garby *et al.* 1987; Goldberg *et al.* 1988; Font-vieille *et al.* 1993; Seale & Conway, 1999; Zhang *et al.* 2002). On the contrary for children, the use of BMR to esti-mate energy expenditure during the night would introduce an overestimate and for elderly, even an underestimate. Thus, the energy cost of arousal, which is the difference between BMR and OMR, is not equal in different age groups. All measurements were performed with the same res-piration chamber and the same ventilated hood system, according to the same protocol. Furthermore, the within-machine variability was checked every week with methanol burning and the variation was always within the narrow limits of 5 % (Adriaens *et al.* 2003). During the BMR measurement, all subjects were continuously observed, and we made sure that subjects were lying motionless, but did not fall asleep. Furthermore, the subjects were instructed to refrain from intensive exercise the day before their stay in the respiration chamber.

Therefore, we believe that the differences in age groups are specifically related to physiological and not to technical reasons.

The elderly reported to sleep worse with more interruptions and toilet visits than adults and children. This applied for the night in the respiration chamber and the home situation. The body movement registration with the accelerometer showed the same. Age-related changes in sleep timing and structure have been long recognized. In summary, the sleep of older people is more frequently interrupted by brief awakenings, and the final awakening occurs at an earlier clock time (Dijk *et al.* 2000). There have been suggestions that the drop in metabolic rate during the night would be the consequence of circadian variations in general metabolic activity. In this case the quality of sleep will not influence the metabolic rate. On the contrary, Fraser *et al.* (1989) concluded that the contribution of sleep and circadian cycle to metabolic rate during the night was approximately equal. Therefore the high OMR compared to BMR, as observed in the elderly, might be caused by the less consolidated sleep. Consequently, the low OMR in children is possibly the result of their sound sleep. When adjusted for fat-free mass, BMR was equal for adults and elderly. However, metabolic rate during the night was higher for adults than elderly, indicating that metabolic rate during the night in elderly is actually mediated by their changed sleeping habits.

During the course of the night a person alternately goes through two different types of sleep called non-rapid-eye-movement sleep and rapid-eye-movement sleep. Within non-rapid-eye-movement sleep, stages 1–3 and delta sleep (stage 4) are recognized in man (Rechtschaffen *et al.* 1966). Older people spend less time in stages 3 and 4 and Brebbia & Alt-shuler (1965) showed that metabolic rate was higher during the stage of rapid-eye-movement sleep, lower in stage 2 and lowest in stages 3 and 4. On the contrary, Webb & Hiestand (1975) found no relationship between sleep stages and meta-bolic rate. Furthermore, Fontvieille *et al.* (1994) found only small differences in energy metabolism during sleep stages. These results suggest that sleep stages play a minor role in the variance of SMR among subjects. Therefore, and because of the restriction the subjects would have experienced when attached to electrodes, we left the sleep stages out of consider-ation in the current study.

SMR_{min} was defined as the lowest metabolic rate during a continuous 60 min period in the night. The ratio SMR_{min}:BMR was 0·82 (SD 0·1) for children while it was 0·93 (SD 0·07) for elderly. Thus, in a period of continuous sleep there is still a significant difference in SMR_{min}:BMR between the age groups. This indicates that the difference in OMR:BMR between the age groups cannot only be attributed to differ-ences in sleeping habits. A different increase in metabolic rate in the morning is of course equally well a possible expla-nation for the difference in OMR:BMR. Vaughan *et al.* (1991) and Fontvieille *et al.* (1993) connected this hypothesis with a change in autonomic nervous system with age. The transition between the sleeping and the basal metabolic state is mediated by both central nervous system and sympathetic nervous system activity. van Baak (2001) concluded in a review that normal or increased levels of sympathetic nervous system activity and reduced reactivity appear to be present in estab-lished obesity. Furthermore, the sensitivity for β-adrenoceptor stimulation is impaired in obesity. The blunted reactivity and sensitivity may contribute to the aetiology and the mainten-ance of the obese state (van Baak, 2001). An increased resting sympathetic nervous system activity is also found in elderly and an age-related change in response to the sympathetic acti-vation is therefore suggested (Schwartz *et al.* 1990; Veith *et al.* 1986). A reduced reaction on the activation of the sympathetic nervous system seems to be present in elderly. This might explain the low difference between BMR and SMR in this age group. Other possible related factors are changed concen-trations in orexins or sex hormones with age. The present study was not focused on these mechanisms and, thus, future investigations on this topic are deserved.

In conclusion, for adults, BMR is an appropriate measure of energy expenditure during sleep. In children, the use of BMR to estimate energy expenditure during the night would intro-duce an overestimate and for elderly an underestimate.

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