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Intra-individual variation in RMR in older people

Megan R. D. Gibbons[1], C. Jeya K. Henry[1]*, Stanley J. Ulijaszek[2] and Helen J. Lightowler[1]

[1] *Nutrition and Food Science Group, School of Biological and Molecular Sciences, Oxford Brookes University, Gipsy Lane Campus, Headington, Oxford OX3 0BP, UK*
[2] *Institute of Social and Cultural Anthropology, University of Oxford, 51 Banbury Road, Oxford OX2 6PF, UK*

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In the factorial estimation of total energy expenditure it is assumed that the intra-individual variation in RMR is small. Little is known about the intra-individual variation in RMR in older subjects. The present study investigated the intra-individual variation in RMR in older people. Measurements of RMR were made in twenty-seven older subjects, mean age 71·6 (SD 6·1) years, on two separate occasions (T1 and T2) and on a third occasion (T3) in nineteen of the subjects. Measurements of height and weight were taken in all subjects. RMR measurements were made in the laboratory using a Deltatrac™ (ventilated-hood indirect calorimeter; Datex, Helsinki, Finland). All subjects had fasted overnight for 12 h and refrained from strenuous exercise before measurements. The intra-individual CV in RMR (kJ/d) after T1 and T2 was 2·5 % in women and 3·6 % in men and was 2·6 % in women and 3·4 % in men after all three sets of measurements. Although mean RMR did not vary across T1, T2 and T3, there was significant 'crossing tracks' across the three measurement occasions in some individuals, reflecting a high degree of within-subject variability. The methods used had a significant measurement error associated with them (high *R* value; significant *F* ratio in three-way ANOVA). In conclusion, the results from the present study indicate that intra-individual variation in RMR was low in older people. The intra-individual variation in the elderly is similar to that seen in younger age groups.

Older people: Resting metabolic rate: Deltatrac™: Reproducibility

People aged >60 years represent an increasing proportion of the population. In the UK, the number of people aged >60 years increased from about 9·1 million in 1971 to 10·7 million in 2000 (Office for National Statistics, 2002). This represents an increase from approximately 16 to 18 % of the population.

RMR has become an increasingly important measurement in determining energy requirements of individuals and populations. RMR represents the largest component of daily energy expenditure (approximately 60–75 %), followed by physical activity (approximately 15–30 %) and diet-induced thermogenesis (approximately 10 %). It has been widely documented that RMR decreases with age, mainly due to a decrease in lean body mass and an increase in body fat (Piers *et al.* 1998; Elia *et al.* 2000). Generally, levels of physical activity are lower in older people; therefore measurements of RMR assume greater significance in predicting the energy requirements of older people.

There is currently some uncertainty in accurately predicting daily energy requirements of older people (Goran & Poehlman, 1992). This is largely due to the paucity of data on energy estimates and RMR for this age group. For instance, the Food and Agriculture Organization/World Health Organization/United Nations University (1985) equations for predicting BMR in older men and women are based on sample sizes of only fifty and thirty-eight subjects respectively. This is a small sample size on which to make assumptions about the general population. Moreover, little is known about the intra-individual variation in RMR in older subjects. In the factorial estimation of total energy expenditure it is assumed that the intra-individual variation in RMR is small. Indeed several reports (Henry *et al.* 1989; Shetty *et al.* 1996) confirm a very small CV in young men over a period of weeks, months and years. Remarkably, there is little information on the intra-individual variation in RMR in the 'older elderly' (>75 years old). Given the increasing prevalence of disease and ill-health in this age group, the intra-individual variation in RMR may be much greater in older people. Assessing and quantifying the intra-individual variation in RMR is important in the factorial estimation of total energy expenditure in older people. The aim of the present study was to determine the technical error of measurement (TEM) and intra-individual variation in RMR in older people.

Methods

Subjects

Twenty-seven older subjects, mean age 71·6 (SD 6·1) years, participated in the main part of the study. The subjects

Abbreviation: TEM, technical error of measurement.

* **Corresponding author:** Professor C. Jeya K. Henry, fax +44 1865 483242, email jhenry@brookes.ac.uk

were seven men (mean age 75·1 (SD 7·0) years) and twenty women (mean age 70·3 (SD 5·3) years). Nineteen subjects (six men (mean age 74·1 (SD 6·8) years) and thirteen women (mean age 69·7 (SD 4·4) years)) agreed to have a third measurement of RMR. All subjects were white non-smokers and the female subjects were postmenopausal; thus, the effects of race (Henry & Rees, 1991), nicotine (Dalloso & James, 1984) and menstrual cycle (Curtis *et al.* 1996; Henry *et al.* 2003) on RMR were excluded. Although the subjects were healthy, some were taking medication during the study period. Subjects were recruited through posters placed in libraries, supermarkets and general practitioners' surgeries, and through a mail-shot. Eligibility criteria for the study included being able to give informed consent and being aged >60 years. The study was approved by the Research Ethics Officer for the School of Biological and Molecular Sciences at Oxford Brookes University.

Measurement protocol

All measurements of RMR were made in the laboratory. RMR was measured using a Deltatrac™ (ventilated-hood indirect calorimeter; Datex, Helsinki, Finland). RMR was determined by measuring O_2 consumption and CO_2 production. The Deltatrac™ was calibrated before each use with Quick Cal™ calibration gas to 5 % CO_2 and 95 % O_2. Ethanol checks were performed every 3–6 months.

All measurements were made by the same trained investigator (M. R. D. G.). Subjects were asked to fast overnight for 12 h and to refrain from strenuous exercise before measurements. Room temperature was maintained at 22–24°C; subjects were asked to rest in the supine position, to minimize movements and to remain awake during the measurement period. Subjects remained under the ventilated hood for a total of 40 min; the first 10 min of readings were excluded as this was taken as the 'settling-in period'. RMR was taken as an average of the readings during the remaining 30 min measurement period. RMR measurements were taken on two separate occasions (T1 and T2) within 1 month of the first measurement in the main part of the study. A third measurement (T3) of RMR was made on nineteen of the twenty-seven subjects. This was completed within 1 month of the T2 measurement.

Measurements were also taken of height (portable digital stadiometer; Soehnle, Murhardt, Germany) and weight (digital weighing scales, accurate to 100 g; Terraillon, chatou Cedex, France) in all subjects. Measurements for height and weight were taken according to Lohman *et al.* (1991). BMI was calculated as weight (kg)/height $(m)^2$. All measurements were taken in triplicate.

Statistical analyses

Statistical analyses were performed using SPSS 10·0 (1999; SPSS Inc., Chicago, IL, USA). Results are expressed as mean values and standard deviations unless stated otherwise. Before statistical analysis, the normality of the data was tested using the Shapiro–Wilks statistic; all data were normally distributed. Comparisons within groups were undertaken using paired *t* tests and between groups using independent sample *t* tests. Anthropometric data were compared with results from the National Diet and Nutrition survey (Finch *et al.* 1998) using one-sample *t* tests. Statistical significance was set at $P<0·05$.

The TEM and coefficient of reliability (R) were determined using equations given by Ulijaszek & Kerr (1999):

$$\text{TEM} = \sqrt{((\Sigma D^2)/2n)}$$

and

$$R = 1 - ((\text{total TEM})^2/\text{SD}^2),$$

where D is the difference between measurements and n is the number of subjects measured.

Replicate measures of RMR were not taken in the present study. In their absence, TEM and CV (%) values reflect total intra-individual variation. There are two components to intra-individual variation in RMR: measurement error and true physiological variation in RMR. These are difficult to separate, the usual way being the use of replicate measurements. In the present study, approximations of replicate measures were obtained by treating each 30 min RMR measure as two 15 min replicates, using missing values for those subjects without a third measurement. The significance of between-subject, between-measurement and between-replicate RMR values was then assessed using a three-way (model II) ANOVA (Sokal & Rohlf, 1969), in the manner used to determine variation in energy intake by Soares *et al.* (1989*a*).

Results

The results from Tables 1 and 2 confirmed previous studies showing that men have a higher absolute RMR than women (5903 (SD 634) *v.* 5344 (SD 511) kJ/d respectively) (Arciero *et al.* 1993; Buchholz *et al.* 2001). The TEM for all twenty-seven subjects was 282 kJ (R 0·80) and for the nineteen subjects measured on three occasions was 239 kJ (R 0·83).

There was a slight decrease in the mean RMR in both male and female subjects between T1 and T2 and an increase for T3. The CV after T1 and T2 of the male (3·6 %) and female (2·5 %) subjects was low and indicated a highly reproducible method of measuring RMR. The CV after all three measurements was comparable with measurements made for T1 and T2 for male (4·0 %) and female (3·0 %) subjects. There was a decrease in mean body weight in both female (0·5 kg, $P=0·024$) and male (0·8 kg, $P=0·355$) subjects between T1 and T2. To account for this, RMR was also expressed as kJ/kg per d (CV 2·4 % for women, 3·8 % for men), but the results were still similar to RMR values expressed as kJ/d.

Table 3 presents results of the three-way ANOVA, showing significant differences between subjects ($P<0·001$) and between replicates of measurement ($P<0·05$), as well as a significant interaction between subjects and the time of measurement (T1, T2, T3). Thus, while there were no significant differences in RMR across times of measurement, measurement error was a significant component of total variation, as reflected in the low value of R (0·83) (Ulijaszek & Lourie, 1994).

Table 1. Intra-individual variation in RMR in male subjects (*n* 7)†

Measurement occasion...	RMR (kJ/d)					CV (%)	
Subject	T1	T2	T3	Mean T1, T2	Mean T1, T2, T3	T1, T2	T1, T2, T3
1	6218	5947	6068	6083	6078	3·2	2·2
2	7176	6716	6051	6946	6648	4·7	8·5
3	6138	6447	6200	6292	6262	3·5	2·6
4	5947	5678	5710	5812	5778	3·3	2·5
5	5257	5324	5206	5290	5262	0·9	1·1
6	4895	4888	–	4891	4891	0·1	–
7	6832	5938	6446	6385	6405	9.9	7.0
Mean	6066*	5848*	5947	5957*	5903*	3·6	4·0
SD	805	627	435	694	634		

Mean values were significantly different from those of female subjects (see Table 2): *$P<0·05$.
† For details of subjects and procedures, see pp. 485–486.

Table 2. Intra-individual variation in RMR in female subjects (*n* 20)†

Measurement occasion...	RMR (kJ/d)					CV (%)	
Subject	T1	T2	T3	Mean T1, T2	Mean T1, T2, T3	T1, T2	T1, T2, T3
8	5172	5274	–	5223	5223	1·4	–
9	5465	5734	5642	5599	5613	3·4	2·4
10	5603	5490	5487	5546	5526	1·4	1·2
11	6040	6214	5916	6127	6057	2·0	2·5
12	5518	5428	–	5473	5473	1·2	–
13	7139	5622	6037	6381	6266	16·8	12·5
14	5996	5363	5924	5679	5761	7·9	6·0
15	5115	4795	–	4955	4955	4·6	–
16	4874	4916	4976	4895	4922	0·6	1·0
17	5303	5345	5342	5324	5330	0·6	0·4
18	4665	4574	–	4620	4620	1·4	–
19	5072	5072	5360	5072	5168	0·0	3·2
20	4762	4775	4992	4769	4843	0·2	2·7
21	4439	4505	–	4472	4472	1·0	–
22	6334	6125	6408	6230	6289	2·4	2·3
23	5499	5497	5467	5498	5488	0·0	0·3
24	5802	5752	–	5777	5777	0·6	–
25	5112	4985	–	5049	5049	1·8	–
26	5059	5160	4914	5109	5044	1·4	2·4
27	5012	4905	5105	4958	5007	1·5	2·0
Mean	5399*	5277*	5505	5338*	5344*	2·5	3·0
SD	634	474	462	527	511		

Mean values were significantly different from those of male subjects (see Table 1): *$P<0·05$.
† For details of subjects and procedures, see pp. 485–486.

Table 3. Three-way ANOVA (type II model) of RMR between three measurement occasions and between first and final 15 min of measurement*

Source	Sum of squares	df	Mean square	*F* ratio	Statistical significance of effect: *P*
Between time of measurement	63671·560	2	31835·780	2·771	NS
Between first and final 15 min of measurement	8770·727	1	8770·727	5·054	0·03
Between subjects	2460530·840	24	102522·118	8·680	<0·001
Time of measurement × first and final 15 min of measurement	7900·573	2	3950·287	2·797	NS
Time of measurement × subjects	551459·440	48	11488·738	8·136	<0·001
First and final 15 min of measurement × subjects	41648·440	4	1735·352	1·229	NS
Time of measurement × first and final 15 min of measurement × subjects	67781·760	48	1412·120		

* For details of subjects and procedures, see pp. 485–486.

Although on average RMR does not vary significantly across T1, T2 and T3, the significant interaction term reflects a high degree of within-subject variability, in that individuals' RMR does not track across the period of measurement (Fig. 1).

Predicted BMR was calculated using equations from the Food and Agriculture Organization/World Health Organization/United Nations University (1985). The mean predicted RMR was 5632 (SD 488) kJ/d in women and 6451 (SD 725) kJ/d in men. Compared with measured RMR values, the Food and Agriculture Organization/World Health Organization/ United Nations University (1985) equations overestimated RMR in sixteen women and six men. In women, RMR was over-estimated by 7 (SD 5) (range 2–20) % and in men by 10 (SD 5) (range 2–18) %.

The heights, weights and BMI of the male and female subjects are shown in Table 4. Intra-individual CV for body weight was 0·6 (range 0·0–2·6) % in women and 1·4 (range 0·0–2·4) % in men. The mean BMI (26·2 kg/m^2) fell within the overweight range (25·0–29·9 kg/m^2). Female subjects had a higher mean BMI than their male counterparts. Four male subjects were classified as normal, two as overweight and one as obese, giving a mean BMI 25·5 kg/m^2, which was within the overweight range. One female subject was classified as underweight, six as normal, six as overweight and seven as obese, which gave a mean BMI 26·5 kg/m^2 (within the overweight range). In all the subjects measurements of height, weight, BMI and grip strength were above the 50th percentile (median) as measured in free-living male and female subjects of the same age group (Finch *et al.* 1998).

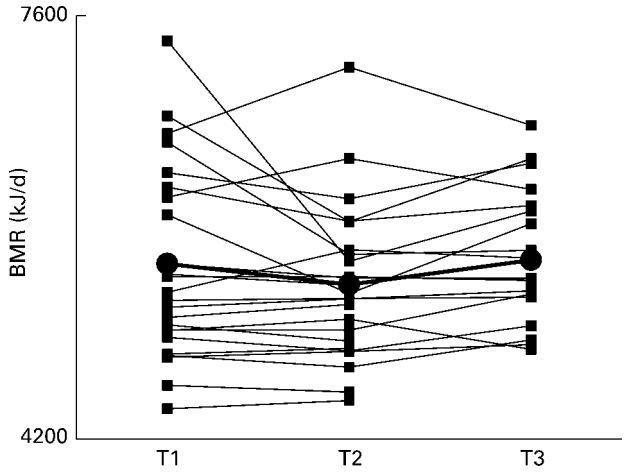

Fig. 1. Variation in individual RMR in older people. T1, T2, T3, measurement occasions. For details of subjects and procedures, see Table 4 and pp. 485–486. –●–, Mean values.

There was no significant difference (P=0·495) in the RMR of medicine users (n 16, 75·0 (SD 8·1) kJ/kg per d) *v.* non-medicine users (n 11, 77·1 (SD 6·8) kJ/kg per d). This suggests that the effect of medicine on metabolic rate was minimal (Henry, 2000).

Discussion

Assessing and quantifying the intra-individual variation in RMR is important in the factorial estimation of total energy expenditure in older people. The present study indicates that intra-individual variation in RMR was low in older people. The study also confirms that the intra-individual variation in older people is similar to that seen in younger subjects. Although on average RMR did not vary across T1, T2, and T3, there was significant 'crossing tracks' across the three times of measurement in some individuals, reflecting a high degree of within-subject variability.

We have little information on the intra-individual variation in RMR in older people. Visser *et al.* (1995) repeated measurements of RMR in older subjects and had a CV of 7·8 and 6·0 % in men and women respectively. These results are somewhat higher than those from the present study. A study by Reilly *et al.* (1993) involved taking repeated measurements of BMR in eleven healthy elderly women using a portable open-circuit indirect calorimeter. The results showed a mean difference of 2·9 (range 0·1–7·2) % between the measurements, which is comparable with the findings in the present study using twenty female subjects (2·5 (range 0·0–16·8) %).

Repeated measurements of RMR in older people appear to be reproducible using the measurement protocol outlined in the present study. However, the methods used did show a significant measurement error associated with them (high R value; significant F ratio in three-way ANOVA). Wells & Fuller (1998) showed that the Deltatrac™ (Datex), used in the present study, is a very precise metabolic monitor and is accurate within 3 % for both gas exchange and energy expenditure. Three subjects had large CV of 9·9, 16·8 and 7·9 % (no. 7, 13 and 14 respectively). These large variations could be due to the subjects being in an anxious state. Other possible reasons could include not having fasted for the full 12 h, being engaged in strenuous activity on the morning of one of the measurements or the onset of illness (Tzankoff & Norris, 1978).

None of the subjects had prior experience of RMR measurements using a ventilated hood. Soares *et al.*

Table 4. Anthropometric data for all subjects*
Means values standard deviations and ranges

	Age (years)			Height (m)			Weight (kg)			BMI (kg/m^2)		
	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
Male	75·1	7·0	(66·5–82·8)	1·75	0·04	(1·70–1·81)	78·1	12·8	(67·7–103·0)	25·5	4·2	(21·9–34·4)
Female	70·3	5·3	(61·8–83·8)	1·65	0·07	(1·49–1·77)	71·6	11·1	(55·1–91·3)	26·5	4·2	(18·8–34·3)
Both	71·6	6·1	(61·8–82·8)	1·67	0·08	(1·49–1·81)	73·3	11·7	(55·1–103·0)	26·2	4·2	(18·8–34·4)

* For details of procedure, see pp. 485–486.

(1989*b*) compared BMR measurements produced by five different machines, including a ventilated hood. He found that there were significant interactions between subjects with the ventilated hood when they were unaccustomed to the apparatus. Despite being unfamiliar with the ventilated hood, the results in our present study were reproducible.

In conclusion, the protocol outlined in the present study for measurement of RMR produced reproducible results in older people. However, it is important to ensure that subjects adhere to the protocol to minimize intra-individual variation in RMR. The intra-individual variation in RMR in the elderly was low and was similar to that seen in younger age groups. This suggests that the use of the factorial method to estimate energy requirements is also applicable in the older population.

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