Resting metabolic rate and the influence of the pretesting environment[1–3]

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ABSTRACT We examined the effect of pretesting environment on measurement of resting metabolic rate (RMR). RMR was measured in 18 older (66.1 ± 1.4 y) individuals after an overnight stay in the Clinical Research Center (ie, inpatient) and after subjects transported themselves to the laboratory (ie, outpatient). Similar measurements were also performed after an 8-wk endurance-training program. RMR was higher ($P < 0.01$) before exercise training in subjects who transported themselves to the laboratory (ie, outpatients; 4.9 ± 0.13 kJ/min) than in inpatients (4.6 ± 0.13 kJ/min) and after exercise training in outpatients (5.4 ± 0.08 kJ/min) vs inpatients (5.0 ± 0.13 kJ/min). Training increased RMR under both inpatient (10%; $P <$ 0.01) and outpatient (11%; $P < 0.01$) conditions. We conclude that RMR is higher when measured under outpatient conditions in older volunteers. Therefore, when daily energy requirements based on the assessment of RMR are being estimated, the pretesting environment should be considered. However, the exercise-training-induced increase in RMR can be detected by using either an inpatient or an outpatient protocol. *Am J Clin Nutr* 1992;55:626–9.

KEY WORDS Resting metabolic rate, exercise, inpatient, outpatient, energy requirements, aging

Introduction

Resting metabolic rate (RMR) is quantitatively the largest component of energy expenditure in humans and constitutes ~60–70% of daily energy expenditure (1). The resurgence of interest in assessing RMR stems partially from its broadened clinical application in nutrient metabolism and in determination of energy requirements as well as the commercial availability of improved equipment for measuring it. Although the experimental conditions for the assessment of RMR are generally thought to be standardized, considerable variation among laboratories exists in the type of indirect calorimetry equipment, nutritional conditions before the determination of RMR, and timing of indirect calorimetry relative to the last exercise session. Several of these issues have recently been examined (2, 3).

One methodological consideration that has not been examined in previous studies is the influence of the environmental setting preceding the determination of RMR. Frequently, the majority of laboratories assess RMR on an outpatient basis, ie, subjects transport themselves to the laboratory on the testing day and measurement is performed after a short period of recumbency in a relaxed atmosphere (4). On the other hand, depending on facilities, other laboratories measure RMR after volunteers have stayed overnight in a hospital or research center in which nutritional intake and physical activity have been strictly controlled. Because RMR is frequently relied on as a method for estimating daily energy needs in population studies (5) as well as in the clinical management of obesity, it is important to identify methodological sources of variation to increase the reliability and precision of this measurement.

The primary purpose of this investigation was therefore to examine the influence of pretesting environment on RMR by performing repeated tests in the same healthy elderly individuals under inpatient and outpatient conditions. These measurements were performed before and after an exercise training program and thus permitted examination of the effects of the pretesting environment on RMR in response to a chronic exercise training stimulus. The latter objective is secondary to the purpose of the present study; we have discussed this aspect in more detail elsewhere (6, 7).

Materials and methods

Subjects

Eighteen older individuals (66 ± 1.4 y, $\bar{x}$ ± SE) (10 males and 8 females) in excellent general health participated in the study. At the start of the study none of the participants were involved in a formal exercise program. Criteria for subject selection were no clinical symptoms or signs of cardiovascular disease, a resting blood pressure < 140/90, a normal resting electrocardiogram (ECG) and a normal ECG during an exercise stress test, absence of any prescription or over-the-counter medication that could affect cardiovascular function, no family history of diabetes or

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obesity, and weight stability (±2 kg) as determined by medical history within the past year. The purpose and possible risks of the study were carefully explained to all subjects before they gave their consent to participate. The experimental protocol was approved by the Committee on Human Research for the Medical Sciences at the University of Vermont.

Experimental design

All subjects were tested in both inpatient and outpatient experimental conditions before and after an 8-wk exercise-training program. For the inpatient determination of RMR subjects were brought to the Clinical Research Center the day before the measurement. Subjects were provided a meal of mixed composition (55% carbohydrates, 30% fat, and 15% protein) at 1730 with an approximate energy content of 4.2 MJ (1000 kcal). Subjects were accustomed to the ventilated hood by actually performing measurements. To alleviate any concern about testing conditions, practice measurements were made the night before actual data collection. Volunteers were urged to be in bed with lights out at 2300, which was verified by the nursing staff. Subjects were first awakened at ~0500 the next morning and allowed to void, if necessary. RMR was performed at 0730 in the same bed in which the volunteers slept as previously described (8). The majority of subjects were awake when indirect-calorimetry measurements were begun and remained awake during the 45-min collection period. Thereafter, body composition and a test for maximal oxygen consumption ($\dot{V}O_2max$) were performed.

For outpatient assessment of RMR, subjects returned to the Clinical Research Center 10 d later. No differences in body weight were noted between inpatient (pretraining, 70.8 ± 2.2 kg; post-training, 70.9 ± 2.2 kg) and outpatient (pretraining, 70.9 ± 2.1 kg; post-training, 70.9 ± 2.1 kg) subjects. Subjects were instructed to fast after dinner the night before testing, to be in bed by 2300, and to transport themselves to the research center in a vehicle. Subjects were also asked to abstain from all vigorous physical activity the day before testing. On arrival at the Clinical Research Center at ~0700, volunteers rested in a sedentary supine position in a darkened room for 30 min and RMR was assessed for 45 min thereafter beginning at ~0730. Because of the nature of the exercise program and the timing of other tests involved in the experiment, volunteers could not be randomly assigned to inpatient and outpatient conditions.

Procedures

All metabolic measurements were performed 48 h after the last exercise session because this time period was shown to eliminate any residual effects from the most recent training session (9). In recent studies we showed that RMR is reproducible in the same individuals when tested under the same experimental conditions (8). The intraclass correlation and CV for RMR determined using test (4.7 ± 0.7 kJ/min) and retest (4.7 ± 0.6 kJ/min) in 17 male volunteers reached 0.90% and 4.3%, respectively (8). Energy expenditure was calculated from the equation of Weir (10).

Body fat was estimated from body density by underwater weighing, with simultaneous measurement of residual lung volume by helium dilution by using the Keys and Brožek equation (11), before and after exercise training. Fat-free weight (FFW) was estimated as body weight minus fat weight. $\dot{V}O_2max$ was estimated by a test to exhaustion, running on a motorized treadmill as previously described (8).

The experimental treatment consisted of cycling exercise three times a week in the morning for an 8-wk period as previously described (6). Briefly, the program consisted of a short warm-up period followed by cycling at an individually prescribed duration and intensity to expend a given number of calories. During the first week subjects exercised three times per week at 60% of their maximal oxygen consumption until 630 kJ (150 kcal) were expended. The intensity and duration were gradually increased during the 8-wk training program so that by the eighth week a net energy expenditure of 1260 kJ (300 kcal) per session was achieved at 85% of $\dot{V}O_2max$. The net energy estimate of exercise was computed from a linear relation between the subjects' heart rate and oxygen consumption established during their test for maximal aerobic power. No injuries or health-related problems arose during the exercise program and no modification of the experimental protocol was required. Subjects were weighed at the beginning of each exercise session to ensure that they were weight stable (±2 kg) during the course of the program. The study was designed to increase cardiovascular fitness and maintain energy balance.

Statistical analysis

A two-way repeated-measures analysis of variance (ANOVA) was performed to assess the differences in RMR between inpatient and outpatient conditions as well as before and after exercise training. Data for males and females were pooled into one group because no gender effect was noted in the magnitude of change in RMR in response to endurance training or between inpatient and outpatient assessment of RMR. All data are expressed as $\bar{x}$ ± SE.

Results

Table 1 shows the physical characteristics of the elderly individuals before and after endurance training. By experimental design no changes were noted in body weight or composition. The only significant change noted was an 11% increase in $\dot{V}O_2max$ ($P < 0.01$).

Figure 1 shows the difference in RMR measurements when measured under the two conditions before and after the exercise training program. Before endurance training outpatient RMR (4.9 ± 0.13 kJ/min) was ~7% greater ($P < 0.01$) than inpatient

TABLE 1
Physical characteristics of 18 older individuals before and after an 8-wk exercise-training program*

Characteristic	Before exercise training	After exercise training
Age (y)	66.0 ± 1.4	
Height (cm)	169.1 ± 2.0	
Weight (kg)	70.8 ± 2.2	70.9 ± 2.1
Body mass index, wt/ht^2	24.8 ± 0.6	24.8 ± 0.6
Percent body fat (%)	24.9 ± 1.5	25.9 ± 1.7
Fat-free weight (kg)	53.0 ± 2.1	52.7 ± 2.2
Fat weight (kg)	17.9 ± 1.1	18.2 ± 1.2
$\dot{V}O_2max$ (L/min)	1.9 ± 0.1	2.1 ± 0.1†

* $\bar{x}$ ± SE.
† Significantly different from before exercise training, $P < 0.01$.

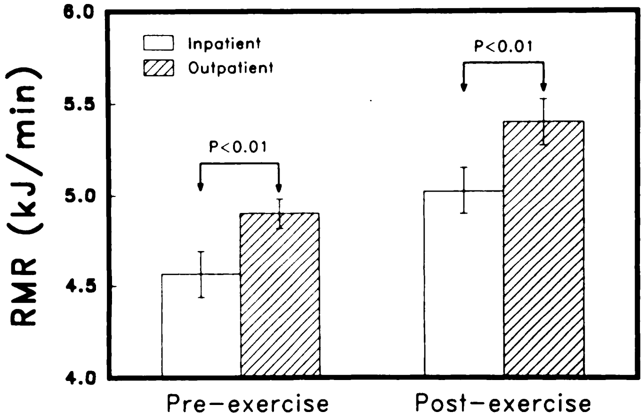

FIG 1. Resting metabolic rate (RMR) measured under inpatient and outpatient conditions as well as before and after an 8-wk endurance-training program in 18 older individuals. Outpatient assessment of RMR was significantly higher than inpatient RMR before and after endurance training ($P < 0.01$).

RMR (4.6 ± 0.13 kJ/min). This difference persisted after endurance training because outpatient RMR (5.4 ± 0.08 kJ/min) was 8% greater ($P < 0.01$) than inpatient RMR (5.0 ± 0.13 kJ/min). Thus, exercise training significantly increased RMR by 11% ($P < 0.01$) under outpatient conditions (pretraining, 4.9 ± 0.13 kJ/min vs post-training, 5.4 ± 0.08 kJ/min) and by 10% ($P < 0.01$) under inpatient conditions (pretraining, 4.6 ± 0.13 kJ/min vs post-training, 5.0 ± 0.13 kJ/min) ($P < 0.01$). Examination of individual data showed that 16 of 18 individuals showed a higher outpatient RMR compared with inpatient RMR before and after exercise training. The fasting respiratory quotient (RQ) was similar ($P > 0.05$) before endurance training under outpatient (0.83 ± 0.001) and inpatient (0.84 ± 0.001) conditions. Similarly, after endurance training outpatient RQ (0.80 ± 0.001) was similar to inpatient RQ (0.79 ± 0.001). Fasting RQ, however, decreased ($P < 0.05$) in response to endurance training under both inpatient and outpatient conditions.

Discussion

The major purpose of this methodological study was to examine the influence of the pretesting environment on the assessment of RMR by comparing indirect-calorimetry measurements performed in inpatient and outpatient experimental conditions in older volunteers. The principal findings are that the outpatient-test experimental condition overestimates RMR compared with the inpatient measurement of RMR and that the magnitude of the exercise-induced increase in RMR is similar under both inpatient and outpatient testing conditions in older people.

Experimental conditions preceding the determination of RMR are generally thought to be standardized. Historically, basal metabolic rate (BMR) was defined as the energy expenditure of an individual 10 h after the last meal while that individual lay quietly at rest at normal ambient and body temperatures and in the absence of either physical or psychological stress (4). The differences between BMR and RMR have never been clearly defined but the inpatient assessment of RMR encompasses all of the aforementioned experimental conditions.

Depending on the availability of facilities, financial resources, and technical staff, investigators measure RMR either on an inpatient or outpatient basis. From a practical standpoint the outpatient assessment of RMR places fewer demands on the volunteers because subjects are not required to stay overnight in the laboratory. Subjects usually arrive after a 10- to 12-h overnight fast, after which RMR is determined in a restful environment. Although outpatient determination of RMR is certainly more convenient for subjects and investigators alike, these experimental conditions increase the likelihood of aberrant measures because of noncompliant volunteers and the possibility that general preparation by subjects (showering, dressing, and transport to the lab) violates "true" basal conditions. One could argue equally, however, that outpatient RMR is more physiologically representative of resting energy expenditure during the day.

In an inpatient setting subjects are usually provided an evening meal and spend the night in the room in which RMR is measured the following morning on awakening. Inpatient assessments ensure greater standardization and confidence over experimental conditions before the determination of RMR (ie, nutritional state and physical activity) but may be more costly (ie, incurring the costs of meals, hospital room, and nursing staff) and inconvenient for volunteers.

In the present study we found that RMR was ≈8% higher when measured under outpatient conditions as compared with inpatient conditions and this difference was consistent before and after endurance training (Fig 1). These findings suggest that when RMR is compared between laboratories investigators should take into consideration the pretesting environment because it is a factor that clearly contributes to differences in RMR in older volunteers. It is likely that the higher RMR measured in the outpatient condition is due to the residual effects associated with the physical activity involved in preparation and transport to the laboratory by the volunteer, leading to an increased state of arousal. Thus, despite the habituation of the subjects to the testing apparatus and the 30-min recumbency period preceding actual data collection, outpatient experimental conditions yield energy-expenditure values that are consistently higher relative to inpatient measurements. Furthermore, we have no evidence that the volunteers violated the fasting conditions as a possible explanation for the higher RMR because the older subjects were found to be very compliant and RQs were representative of fasting substrate oxidation.

Because of the differences in energy expenditure in the outpatient and inpatient experimental protocols, it is suggested that more appropriate terminology be used to reflect the specific testing conditions. We would like to suggest that the term BMR (ie, the lowest metabolic rate in an awakened state) be used by investigators that measure metabolic rate on an inpatient basis, whereas RMR is more appropriate for measurements performed on an outpatient basis.

In the present experiment a methodological caveat should be noted. Volunteers could not be randomly assigned to the experimental conditions (before vs after training and inpatient vs outpatient conditions) because of the progressive nature of the exercise program and the timing of other tests involved. We believe, however, that this does not compromise the interpretation of our findings. If an order effect had been present, one would have expected to find the highest RMR during the inpatient visits, given the fact that these tests preceded the outpatient measurements, and, thus, the apprehension associated with the novelty of testing conditions would have been increased. Furthermore, the fact that RMR was higher both before and after endurance training and the high degree of reproducibility of our measurements lends confidence that this is a true finding and not an artefact of the experimental design.

The present finding of a reported difference between pretesting environments on RMR has important implications for the determination of resting energy requirements. The currently recommended guidelines of the World Health Organization (5) suggest that daily energy requirements can be estimated based on the assessment of BMR and its multiplication by a fixed physical-activity factor. It is unclear, however, whether these recommendations are based on outpatient or inpatient assessment of RMR, and this difference in pre-experimental conditions would lead to a discrepancy of 8% in the estimated daily individual energy requirements. For example, for an individual with an activity factor of 1.5, the discrepancy in daily energy requirements would be equivalent to 175 kcal/d. On the basis of the present findings, we suggest that the cumulative daily energy cost of RMR be calculated by using a factorial approach given the energy cost and related contribution of the sleeping metabolic rate, the RMR measured on awakening, and the metabolic rate in the aroused state.

We also found a significant 10% increase in RMR under both inpatient and outpatient conditions after the endurance-training program and this is consistent with previous data from our laboratory (6, 7). As previously discussed, it is unlikely that this increase represents the residual effects of the last exercise bout because RMR was measured 48 h after the last exercise session (9). We suggested previously that the increased RMR after endurance training is mediated by a high-flux energy state in which individuals match an increase in energy intake to a proportional increase in energy expenditure (6). We showed before that approximately one-half of the variation in changes in RMR in response to endurance training is accounted for by increases in food intake and in the rate of norepinephrine appearance in circulation (6, 7), suggesting that both nutritional and sympathetic factors mediate change in metabolic rate in response to endurance exercise. Whatever the mechanism of the elevated RMR in response to endurance training, the present data suggest that significant differences within individuals in RMR could be detected by either inpatient or outpatient testing protocols. Therefore, when an intervention design is being considered, the choice of inpatient or outpatient status is not a methodological concern when changes in RMR within individuals are being measured.

In summary, we found that outpatient conditions overestimate RMR relative to inpatient assessment of RMR. This factor should be taken into account when results are compared between laboratories and when daily energy requirements based on measures of resting energy expenditure are being evaluated. Furthermore, the magnitude of increase in RMR after endurance training in older individuals is a consistent finding in both outpatient and inpatient conditions.

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