Characteristics of Energy Metabolism in Males with Mental Retardation

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Summary To characterize the energy metabolism in individuals with mental retardation (MRs), we measured energy cost at several physical activity levels (basal, supine, sitting, standing, and walking at 30, 50 and 70 m/min), maximal oxygen consumption (\(\dot{V}O_2\)max), and body composition in 23 male MRs and the same number of volunteer male controls. Both groups were individually matched for age, body height, and body weight. Energy cost was measured by the Douglas bag technique. The recently developed sulfur hexafluoride (SF6) dilution technique was employed for measuring body composition. In addition, 3-dimensional accelerometry was used for evaluating body movements, and plasma indices of macronutrients were also measured. The energy cost of MRs, when sitting, standing, and walking at 30 and 50 m/min, was significantly higher than that of controls (\(p<0.05\)), while the basal and resting metabolic rates were similar in both groups. \(\dot{V}O_2\)max was significantly lower (\(p<0.05\)) in MRs than controls. Accelerometry demonstrated excessive movement by MRs, which may explain their higher energy cost of exercise. In contrast, no significant difference was observed in percent body fat or lean body mass. Concentrations of plasma total cholesterol, triacylglycerols and albumin were significantly lower in MRs as compared with the controls. Our findings suggest that MRs are burdened with an energy metabolism less economical than non-MRs. Limited physical activity in their daily life may be the cause. These characteristics of MRs' energy metabolism should be considered for planning their proper dietary schedules and physical activity programs.

Key Words energy cost, mental retardation, \(\dot{V}O_2\)max, body composition, sulfur hexafluoride dilution

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The physical conditions of individuals with mental retardation (MRs) need to be well characterized so that MRs can be provided with effective assistance. Specifically, knowledge about their energy metabolism is indispensable for planning proper dietary schedules and physical activity programs for them. Nevertheless, only few studies have appeared so far which investigate the energy expenditure of MRs.

Physiologists have partitioned energy expenditure into several components; basal metabolic rate (BMR) or resting metabolic rate (RMR), physical activity, and thermogenic effect of food or adaptive thermogenesis (I). In Japan, these components in MRs are usually estimated using the data obtained from healthy persons. This could be misleading because previous data suggest that MRs have low levels of physical fitness (2–6), a higher incidence of obesity (7–11), and may respond differently to exercise training than persons without mental retardation (12). To examine such possibilities and characterize the energy metabolism in MRs, we measured the energy expended at rest and in some types of physical activity by means of indirect calorimetry with the Douglas bag technique (13), and compared the results of MRs with those of healthy control subjects. In addition, we examined several factors which might be related to energy cost such as maximal oxygen consumption (\( \text{Vo}_2\text{max} \)), lean body mass (LBM), body fat, and plasma concentrations of macronutrients. The recently developed SF\(_6\) dilution method was employed to attain reliable measurements of body volume in MRs, for whom the underwater weighing method (UWW) is too stressful and effort-requiring to follow. Body movements of MRs were also analyzed using a 3-dimensional accelerometer which helps to evaluate fine movements in a quantified manner.

MATERIALS AND METHODS

Subjects

Twenty-three male MRs aged 18–49 y (mean = 36.3 y) were enrolled from two tertiary care mental retardation institutions in Ibaraki Prefecture, northeast of Tokyo. MRs were diagnosed as persons whose intelligence quotient (IQ) was 70 or less, as is described in the 4th edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV) (14). The IQ levels of MRs were judged according to the Tanaka-Binet method, and the mean and standard deviation ranges were 35.5±10.3 and 21–59. Subjects were excluded from the study if they had a specific cause of mental retardation (e.g., Down’s syndrome), had a chronic disease (e.g., cardiac, renal, gastrointestinal, hepatic or congenital diseases), received a medication that might affect growth or body composition (e.g., steroids or thyroxine), plasma lipid levels (e.g., diuretics), or possessed any identifiable motor disabilities. Twenty-three healthy males from general populations in Ibaraki Prefecture where the examined MRs used to live before they were admitted to the centers were recruited to be controls. Control subjects were individually paired and matched with MRs for age (±3 y), height (±4 cm) and weight (±9 kg) (Table 1). The sample

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Table 1. Characteristics of the subjects.¹

|                           | Subjects with mental retardation (MR) | Healthy volunteers (Control) | p value² |
|---------------------------|--------------------------------------|-----------------------------|----------|
| Age (y)                   | 36.3 ± 8.9                           | 36.3 ± 8.0                  | 1.00     |
| Height (cm)               | 164.2 ± 4.1                          | 164.4 ± 3.7                 | 0.65     |
| Weight (kg)               | 62.4 ± 12.6                          | 63.6 ± 6.9                  | 0.68     |
| Intelligence quotient (IQ)| 35.5 ± 10.3                          | — ³                         | — ³      |

¹ Values are M ± SD (n = 23).
² Paired t-test.
³ Data not available.

size was determined on the basis of our preliminary study in which the difference of \( \bar{V}o_2 \) between the two groups was 1.01 mL/min/kg (SD = 1.73) when walking at 30 m/min (unpublished data). In order to show this difference at the levels of \( \alpha = 0.05 \) and \( \beta = 0.20 \), the sample size had to be 23 subjects for each group.

Informed consent was obtained from the subjects or their parents or legal guardians. Approval for this study was granted by the Ethical Review Committee at the Medical Research Institute of Tokyo Medical and Dental University.

Protocol

The study was divided into 4 phases. All phases were conducted in a laboratory and gymnasium on the campus of one of the centers. Phase 1 consisted of laboratory familiarization, including demonstrations of the equipment and testing procedures. The physical conditions of the subjects were examined by a physician, with blood pressure being checked and electrocardiogram taken. Phase 2 involved training the subjects to walk on the floor at a constant speed, to use the bicycle ergometer and to breathe through the respiratory collection system. Phase 3 was carried out early in the morning after fasting for at least 10 h, with BMR and pulse rate being measured immediately after the subjects awoke. After BMR measurements, subjects urinated, and anthropometric measurements and collection of blood samples were made. Then in the gymnasium, \( \bar{V}o_2 \) and heart rate (HR) were measured in the supine position (RMR), and when sitting, standing and walking. Phase 4 involved the bicycle ergometry, which was conducted on the day following phase 3.

Estimation of energy cost

The energy cost (kJ per body weight per min) was estimated by indirect calorimetry with the Douglas bag technique (13). The oxygen and carbon dioxide contents of expired air were measured with an expired air analyzer (Expired Gas Monitor 1H26, NEC Medical Systems, Tokyo, Japan). The energy cost was calculated from oxygen consumption (\( \bar{V}o_2 \)) and carbon dioxide production (\( \bar{V}co_2 \)) using the method of Weir (15). Gas volume was measured with a dry gas meter.
(DC-5A, Shinagawa Factory, Tokyo, Japan) and the measurements were corrected for temperature, pressure, and humidity. The BMR was measured by collecting expired air in two consecutive 7-min samples. The subjects were gathered into a gymnasium 2 h after a light breakfast, and rested, lying for 30 min. Then expired air was collected to estimate the energy costs at supine, sitting, and standing positions for 10, 5, and 5 min, respectively.

Energy cost was then measured as subjects walked at 30, 50, and 70 m/min. Each speed was maintained over 4 min and expired air was collected for the last 2 min of each level. Subjects walked along a track of 60 m in circumference, which was equipped with timing lights at 2 m intervals which lit in sequence and led subjects at the desired pace (Paceleader, PL-100C, Yagami Co., Nagoya, Japan). To further ensure maintenance of the pace, a trained staff member was assigned to walk with each subject, while another staff member checked the speed with a stopwatch. An additional observer counted the stride frequency of the subjects at each speed. Subjects started at an initial pace of 30 m/min. Each speed was maintained for 4 min and was increased to the next higher one, with the totally elapsed time of the trial being 12 min.

Measurement of movement by accelerometer

Since we had a strong impression that MRs walked clumsily, we recorded the body movements of MRs and controls using an accelerometer (Activetracer, AC-300, GMS Co., Tokyo, Japan), which recorded the averaged magnitudes of 3-dimensional acceleration vectors every 20 s. The device was designed so small and light (approximately 100 g) that it could be set on the back of a subject at the center of the Jacoby line, without interrupting any movement while he was sitting, standing or walking for calorimetry. Analyzable data were recorded from 17 MRs and 16 controls.

Possible determinants of energy cost

Cardiorespiratory parameters: The stress test was performed by means of submaximal, continuous incremental bicycle ergometry. Since it was extremely difficult for MRs to keep pedaling at a constant rate, a computer-controlled bicycle ergometer (FFS, Bridgestone Cycle Co., Tokyo, Japan) was used. This machine was designed to keep the work rate constant by changing the load continuously according to the pedaling speed. Each subject exercised at three workloads that corresponded to 40, 50 and 60% of his own \( \dot{V}O_2 \) max estimated from his age. The average exercise loads actually given were 45, 62, and 86 W for MRs, and 64, 85 and 102 W for controls. Each loading level continued for 4 min (12 min in total), and expired air was collected for the last one minute of each level. A regression line was made from the HRs and oxygen consumption at the three loading levels. Then with the assumption that the maximal heart rate (HRmax, beats/min) could be calculated as 220 minus the subject's age in years, the \( \dot{V}O_2 \)max was estimated as the oxygen consumption at HRmax.
HR was monitored continuously by a telemeter with three chest loads (Biomulti 100, PN1721, NEC Medical Systems, Tokyo, Japan) and was recorded every minute during the calorimetry, except for the measurement of BMR where the pulse rate was taken at the left or right radial artery by a trained staff member.

**Body composition**

Height, weight, skinfold thicknesses and circumferences at various sites were measured by a trained staff member according to standard procedures (16). The cross-sectional areas of limb fat and muscle were derived from skinfold and limb circumference measurements (17). Body volume was determined by a gas dilution technique, the sulfur hexafluoride (SF₆) dilution method (18). A closed chamber characterized by a mummy-like contour contained the subject in swimwear, and a known amount of SF₆ gas was diffused until equilibrium was attained. The body volume was derived from the following equation: \( V = V_0 + V_1 - \frac{(V_1 \times 10^6)}{X} \); \( V_0 \) being the volume of the chamber (195 L), \( V \) being the body volume of the subject, and \( V_1 \) being the amount of diffused SF₆ after attaining equilibrium. Therefore, the concentration of SF₆ gas (\( X, \text{ ppm} \)) is: \( X = \frac{V_1}{(V_0 - V + V_1)} \times 10^6 \). Two consecutive measurements were routinely made. If the difference between the first and second volumetric values did not exceed 0.5%, the average of the two values was recorded. If the value exceeded 0.5%, an additional measurement was taken and the average of the two closest values was recorded. The percent body fat was calculated by using the equation of Brožek et al (19), and LBM was calculated as body weight minus fat mass. In our preliminary study, the correlation coefficient was 0.9995 (\( y = 1.0047x - 1.5532 \)) between body volume by UWW (\( y \)) and that by SF₆ dilution (\( x \)), and the average of the coefficients of variation was 1% among 12 healthy subjects (unpublished data). Thus, the SF₆ dilution method proved to be valid and reproducible.

**Plasma concentrations of macronutrients**

To assess the plasma concentrations of macronutrients, (i.e., carbohydrate, protein and fat), the following items were measured by the methods noted in the parentheses; plasma glucose (electrode method), insulin (radioimmunoassay second antibody), albumin (brom cresol green), albumin-globulin ratio, total cholesterol (enzymatic assay), high-density lipoprotein cholesterol (dextran-sulfate and phosphotungstic acid with magnesium) and triacylglycerols (enzymatic assay without glycerol blank).

**Statistical analysis**

Means and standard deviations were calculated for all variables. Paired Student’s \( t \)-test was used to determine if significant differences existed between the mental retardation and control groups. Analysis of covariance (ANCOVA) was used to adjust the effect of possible confounding variables by adopting these factors as covariates. Values for subscapular skinfold thickness, thigh skinfold thickness,
Table 2. Energy cost by calorimetry.  

| factor                        | MR      | Control  | p value$^2$ |
|-------------------------------|---------|----------|-------------|
| Basal metabolic rate (BMR)    | $0.067 \pm 0.011$ | $0.065 \pm 0.008$ | 0.51        |
| Supine (RMR)                 | $0.076 \pm 0.011$ | $0.071 \pm 0.008$ | 0.18        |
| Sitting                      | $0.088 \pm 0.013$ | $0.075 \pm 0.009$ | 0.002       |
| Standing                     | $0.093 \pm 0.018$ | $0.080 \pm 0.013$ | 0.003       |
| Walking (30 m/min) (strides/min) | $(86.1 \pm 11.6)$ | $(76.0 \pm 10.2)$ | (0.001)     |
| Walking (50 m/min) (strides/min) | $(106.3 \pm 10.3)$ | $(98.5 \pm 8.1)$ | (0.005)     |
| Walking (70 m/min)$^3$ (strides/min) | $(120.2 \pm 9.2)$ | $(112.0 \pm 10.1)$ | (0.003)     |

$^1$ Values are M ± SD ($n=23$), kJ/kg body wt/min.

$^2$ Paired t-test.

$^3$ It should be noted that almost all the MRs could not keep up with the speed of 70 m/min (see results).

calf skinfold thickness, plasma insulin, plasma total cholesterol and plasma triacylglycerols were found to follow log-normal distribution approximately. Paired t-test was performed after converting them to logarithms. All the statistical analyses were performed using SPSS version 6.1 (SPSS. Inc. Chicago, II, USA).

RESULTS

Estimated energy cost

As shown in Table 2, a statistically significant difference was observed in the energy cost estimated by indirect calorimetry when sitting, standing and walking at the speeds of 30 and 50 m/min, being higher in the MRs than in the healthy control subjects. In contrast, no significant difference was observed for estimated BMR or RMR. It should be noted that most MRs could not keep walking at 70 m/min and their actual speed fell to between 50 and 70 m/min. The energy cost of MRs underestimated in this condition failed to show a significant difference from that of controls who were actually walking at 70 m/min.

Energy cost related factors

Whether expressed as per kilogram body weight or per LBM, $\dot{V}O_2$max was significantly lower in MRs than in the control subjects ($p<0.05$, Table 3). The HRs when sitting, standing and walking at the speeds of 30, 50 and 70 m/min were significantly higher in MRs than in the control subjects, whereas HRs at the time of BMR and RMR measurements were similar between the two groups (Table 3).

Acceleration, recorded as an averaged magnitude of 3-dimensional acceleration vectors and adjusted for age, body height and weight, and stride frequency was...
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Table 3. Maximal oxygen consumption (\(V_O_2\)max) and heart rate.\(^1\)

|                          | MR       | Control  | \(p\) value\(^2\) |
|--------------------------|----------|----------|-------------------|
| **\(V_O_2\)max**        |          |          |                   |
| (mL/kg body wt/min)      | 34.0 ± 9.0 | 41.3 ± 10.0 | 0.039             |
| (mL/kg LBM/min)         | 41.8 ± 11.1 | 50.7 ± 9.5  | 0.038             |
| **Heart rate (beats/min)** |        |          |                   |
| Basal metabolic rate (BMR)\(^3\) | 60.0 ± 6.2 | 60.5 ± 6.3  | 0.82              |
| Supine (RMR)            | 63.8 ± 10.7 | 58.0 ± 8.1  | 0.060             |
| Sitting                 | 71.4 ± 9.1  | 61.8 ± 8.8  | 0.001             |
| Standing                | 78.9 ± 11.0 | 68.2 ± 9.8  | 0.001             |
| Walking (30 m/min)      | 85.8 ± 14.4 | 74.5 ± 10.1 | 0.007             |
| Walking (50 m/min)      | 93.0 ± 15.6 | 79.6 ± 10.3 | 0.004             |
| Walking (70 m/min)      | 101.6 ± 19.1 | 86.8 ± 9.0  | 0.003             |

1 Values are M ± SD (n = 23). LBM, Lean body mass.
2 Paired \(t\)-test.
3 Pulse rate.

Table 4. Body movements while sitting, standing and walking.\(^1\)

|                          | MR (n = 17) | Control (n = 16) | \(p\) value\(^2\) |
|--------------------------|-------------|------------------|-------------------|
| Sitting                  | 0.037 ± 0.049 | 0 ± 0            | <0.001\(^3\)     |
| Standing                 | 0.064 ± 0.048 | 0 ± 0            | <0.001\(^3\)     |
| Walking (30 m/min)       | 1.41 ± 0.21  | 0.95 ± 0.18      | <0.001\(^4\)     |
| LSM\(^2\)                | 1.43        | 0.93             | <0.001            |
| Walking (50 m/min)       | 2.42 ± 0.44  | 1.72 ± 0.34      | <0.001\(^4\)     |
| LSM\(^2\)                | 2.39        | 1.75             | <0.001            |
| Walking (70 m/min)       | 3.46 ± 0.77  | 2.60 ± 0.58      | 0.001\(^4\)      |
| LSM\(^2\)                | 3.39        | 2.67             | 0.005             |

1 Values are M ± SD, m/s\(^2\); the averaged magnitude of the 3-dimensional acceleration vector.
2 Least-squares means by ANCOVA where age, stride frequency, body height and weight are adopted as covariates.
3 Fisher’s exact test (2-tail) where acceleration is classified as zero (below the sensitivity of the accelerometer) or nonzero.
4 Unpaired \(t\)-test.

Since not all of the subjects received this examination, unpaired comparisons were made here.

significantly higher in MRs than in the control subjects when walking at 30, 50 and 70 m/min (Table 4). Interestingly, the accelerometer recorded very small movements among MRs in sitting and standing positions, which were not observed for control subjects (Table 4). Stride frequency at the speeds of 30, 50 and 70 m/min

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Among indices of fat-free mass, the means of circumferences at forearm and calf, as well as those of muscle areas at the mid-upper arm and calf, were significantly lower in MRs than in the control subjects (Table 5). LBM measured by SF₆ dilution method was similar between both groups. None of the fat mass indices showed a significant difference between MRs and the control subjects. As for the distribution of body fat, a higher waist-thigh ratio was observed in MRs than in the control subjects at the suggestive level (0.05 < p < 0.1).

### Table 5. Body composition.¹

| Indices of fat-free mass                      | MR          | Control     | p value² |
|----------------------------------------------|-------------|-------------|----------|
| LBM (kg)⁴                                   | 50.7 ± 8.2  | 52.2 ± 5.7  | 0.47     |
| Circumferences (cm)                          |             |             |          |
| Upper arm                                   | 27.9 ± 3.7  | 29.4 ± 2.0  | 0.092    |
| Forearm                                     | 25.5 ± 2.1  | 26.7 ± 1.3  | 0.015    |
| Waist                                       | 77.7 ± 11.3 | 77.4 ± 6.7  | 0.912    |
| Abdomen                                     | 81.0 ± 11.6 | 79.3 ± 7.0  | 0.54     |
| Hip                                          | 88.8 ± 6.8  | 89.4 ± 4.3  | 0.72     |
| Thigh                                       | 49.7 ± 5.1  | 51.8 ± 3.6  | 0.11     |
| Calf                                        | 34.9 ± 3.1  | 36.5 ± 2.1  | 0.026    |
| Limb muscle area (cm²)                      | 45.9 ± 7.9  | 51.4 ± 6.4  | 0.007    |
| Upper arm muscle area                       | 167.7 ± 27.5| 180.0 ± 25.1| 0.12     |
| Thigh muscle area                           | 83.7 ± 13.1 | 92.7 ± 10.4 | 0.006    |
| Calf muscle area                            |             |             |          |
| **Indices of fat mass**                     |             |             |          |
| BMI (kg/m²)                                 | 23.1 ± 4.1  | 23.5 ± 2.5  | 0.66     |
| Percent body fat (%)⁴                       | 19.7 ± 6.3  | 17.1 ± 5.8  | 0.19     |
| Skinfold thicknesses (mm)                   |             |             |          |
| Triceps                                     | 12.8 ± 7.0  | 12.8 ± 5.4  | 0.98     |
| Subscapular³                                | 15.8 ± 8.1  | 15.6 ± 6.0  | 0.78     |
| Thigh³                                      | 12.5 ± 6.4  | 13.8 ± 7.0  | 0.55     |
| Calf³                                       | 8.2 ± 4.1   | 7.9 ± 2.9   | 0.96     |
| Limb fat area (cm²)                         | 17.3 ± 11.2 | 17.7 ± 7.9  | 0.90     |
| Upper arm fat area                          | 30.8 ± 18.1 | 34.3 ± 17.6 | 0.51     |
| Thigh fat area                              | 14.1 ± 7.9  | 13.9 ± 5.3  | 0.92     |
| Calf fat area                               |             |             |          |
| Fat distribution                            |             |             |          |
| Waist-hip ratio                             | 0.87 ± 0.07 | 0.86 ± 0.05 | 0.72     |
| Waist-thigh ratio                           | 1.56 ± 0.12 | 1.50 ± 0.11 | 0.078    |

¹ Values are M ± SD (n = 23).

² Paired t-test.

³ Log transformed values are used in the analysis, but actual values are presented.

⁴ Values determined by the SF₆ dilution method.
Table 6. Plasma concentrations of glucose, insulin, albumin and lipids.1

|                | MR               | Control          | p value2 |
|----------------|------------------|------------------|----------|
| Carbohydrate   |                  |                  |          |
| Glucose (mmol/L) | 5.0±1.3          | 5.0±0.4          | 0.87     |
| Insulin (pmol/L)3 | 46.7±15.1        | 51.0±22.3        | 0.48     |
| Protein        |                  |                  |          |
| Albumin (µmol/L) | 62.3±4.1         | 64.6±4.2         | 0.034    |
| Albumin-globulin ratio | 1.36±0.14 | 1.55±0.16       | <0.001   |
| Lipid          |                  |                  |          |
| Total cholesterol (mmol/L)3 | 4.0±0.4        | 5.4±1.0          | <0.001   |
| HDL cholesterol (mmol/L) | 1.4±0.4        | 1.5±0.4          | 0.44     |
| Triacylglycerols (mmol/L)3 | 7.6±3.1        | 13.6±7.4         | 0.001    |

1 Values are M±SD (n=23).
2 Paired t-test.
3 Log transformed values are used in the analysis, but actual values are presented.

The means of plasma total cholesterol and triacylglycerols were much lower in MRs than in the control subjects (Table 6). The plasma concentrations of albumin and albumin-globulin ratio were also lower in MRs than in the control subjects, while glucose and insulin measured after overnight fasting were not different between the MRs and control subjects (Table 6).

DISCUSSION

This is, to our knowledge, the first systematic study on the energy metabolism of MRs. The experiment was designed in a case-control manner with individual matching for age, height and weight. Technical improvement was pursued by employing a recently developed SF6 dilution method for assessing the body composition and 3-dimensional accelerometry for measuring body movement quantitatively. The results clearly showed an elevated energy cost in MRs under non-resting conditions (Table 2). Elevation was observed even under mild tasks such as sitting, standing, and walking as slowly as 30 m/min, but not for BMR and RMR, which suggests a very limited capacity for MRs when performing physical tasks.

One possible explanation for the elevated energy cost of MRs is a poor ability to coordinate the body parts when performing physical tasks, which was noticed as a “clumsy” walk. This impression was proved in a quantified manner by measurement of stride frequency and acceleration. Since energy cost, when walking at a fixed speed, is minimized at a preferable stride frequency and increases accordingly as the frequency deviates from there (20), more frequent strides by MRs probably elevate the energy cost. Having a significantly smaller calf circumference and calf muscle area than the control subjects, MRs may have
difficulty in walking with strides as wide as their control counterparts. In addition, the higher acceleration observed when MRs walk indicates that they need more movement and, therefore, consumed more energy than the control subjects. Also, the elevated energy costs when sitting and standing are probably due to small movements by the MRs, which were not observable to the eyes but were recorded by the accelerometer. MRs might be making a greater effort to keep their posture than the control subjects when sitting and standing. It is unclear how hereditary and environmental factors contribute to such poor coordination. Whatever the mechanism is, poor physical skill with elevated energy costs may discourage MRs from physical exercise, which can lead to the formation of a vicious circle between a sedentary lifestyle and limited physical capacity.

The significantly lower $\dot{V}O_{2,\text{max}}$ in MRs observed in our study (Table 3) is probably a result of such a vicious circle. This finding is in good agreement with previous reports (2-6). In those studies, the low level of cardiorespiratory fitness in MRs was explained by their physical inactivity in daily life and by their psychological limitations. Several studies reported that aerobic exercise programs improved the cardiorespiratory functions of MRs and brought their $\dot{V}O_{2,\text{max}}$ values close to normal (6, 21-23). On the other hand, Bar-Or et al (2), Reid et al (24), and Seidl et al (25) noted that physical inactivity could be attributed to limitations inherent to MRs such as poor motor skills and lack of coordination. Lack of motivation in MRs due to their poor understanding of the purpose (3, 24, 26) may also keep them from exercising. In our study, we had to encourage the MRs to make maximal efforts in pedaling the bicycle ergometer. Some of the MRs would discontinue pedaling at moderate intensity (e.g., 60% of the assumed $\dot{V}O_{2,\text{max}}$). The difference of $\dot{V}O_{2,\text{max}}$ might partly explain the difference in energy expended at non-rest between the two groups, since the differences were significantly correlated with each other ($r=0.253-0.652$). However, we found no physiological mechanism for them.

In addition to the lower maximal cardiorespiratory fitness demonstrated by lower $\dot{V}O_{2,\text{max}}$, HR when walking was higher in MRs than in the control subjects. This might also suggest a poor level of physiological response to workload by MRs. A higher HR for MRs was also exhibited in supine, sitting and standing positions. Again this may be due to the physical inactivity of MRs, because it is reported that physically inactive individuals show higher HR at rest than those who are more active in their daily life (27).

Plasma concentrations of macronutrients are known to be affected by lifestyles, particularly diet. Hence, the average levels of major nutrients which were provided for MRs were estimated on the menus in our MR centers during the months of April and May 1996. Servings and plate waste for MRs were checked routinely in the centers, and it was confirmed that MRs were consuming all of the offered meals. MRs were assumed to have 8,987kJ (2,148 kcal)/d of energy, 91.1g/d of protein and 51.2g/d of fat (animal fat: 29.7g/d or 58%), 1.2 of the ratio of polyunsaturated fat to saturated fat (P/S ratio). These amounts are similar to those observed in

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the normal Japanese male population of the same age. According to the Japanese National Nutrition Survey in 1990, the average intake of energy was 8,477 kJ (2,026 kcal)/d: 80.2 g/d for protein and 56.9 g/d for fat (animal fat accounting for 27.5 g/d or 48.3% of total fat) (28). Several dietary surveys in Japan, using a 24-h recall method, reported that P/S ratio ranged from 1.0 to 1.5 (29). Therefore, it is unlikely that the significantly lower plasma concentrations of total cholesterol, triacylglycerols and albumin in MRs are caused by dietary habit. In addition to diet, smoking and alcohol consumption may affect the plasma concentrations of lipids. The frequency of smokers with 20 cigarettes/d or over was 18.5% for MRs and 30.0% for control subjects, and that of drinkers with 2 drinks/d or over (approximately 24 g of alcohol or more) was 7.4% for MRs and 50.0% for control subjects. The difference in drinking habit was reflected in plasma concentrations of γ-GTP, being 18.2 ± 16.0 IU in MRs and 48.3 ± 59.3 IU in control subjects (p < 0.01 by paired t-test using log transformed values). Even when these possible confounders were adjusted by ANCOVA (data not shown), the difference in plasma, as above for macronutrients, remained significant except for albumin. Thus, these lifestyle factors do not adequately explain the lower plasma concentrations of total cholesterol and triacylglycerols in MRs. Although the precise mechanism remains unclear, the metabolic function inherent in MRs might be related to the higher energy cost at non-rest. Several studies revealed that the concentrations of plasma or serum cholesterol, triacylglycerols and albumin were lower in MRs than in non-MR subjects (30–32), although another study focusing on Down's syndrome reported no change in these items (33). According to a study by Tint GS et al, both abnormally low plasma cholesterol concentrations and marked elevation of 7-dehydrocholesterol were observed in five patients with Smith-Lemli-Opitz syndrome (34). The combination of low cholesterol and high 7-dehydrocholesterol was considered to point to a major block in cholesterol biosynthesis, at the step in which the C-7(8) double bond of 7-dehydrocholesterol was reduced forming cholesterol. This biochemical study suggests that host factors might be causative of extremely low concentrations of cholesterol in MRs. The low albumin-globulin ratio observed in MRs, taken together with the low muscle area of the upper arm and calf, may indicate a mild protein deficiency occurring in the subjects, toward which detailed studies should be addressed in the future.

From an epidemiological point of view, assessment of daily energy cost is necessary not only to establish the energy requirement as a reference value for dietary intake but to explore the hypothesis that physical activity protects people from cardiovascular diseases, and conversely, that sedentary living predisposes them. If the energy costs (EC) at various physical activity levels are available, daily energy expenditure (DEE) is calculated on the basis of time-motion study or time-task analysis: DEE = (ΣEC × min) × body weight. As for MRs, however, there has been no datum reported on energy cost. Our findings on the metabolic pattern characteristics of MRs can contribute to future research where the ideal dietary intake, physical exercise, and body weight for MRs is explored.
In summary, this study has clearly shown that MRs have higher energy cost in performing physical tasks, even very mild ones, as compared with normal control subjects. Although the precise mechanism remains unclear, it is most likely that a sedentary lifestyle, observed commonly among MRs, may be causative of their low physical capacity and high energy cost. Also some unknown metabolic abnormality, as is suggested by low levels of cholesterol, triacylglycerols, albumin-globulin ratio, mid-upper arm muscle area and calf muscle area, may be responsible for the high energy cost in MRs. Further study is needed to clarify these mechanisms as well as to investigate MRs with higher obesity or lower IQ.

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