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Total energy expenditure of elite synchronized swimmers measured by the doubly labeled water method

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Abstract To determine the daily energy requirement of elite synchronized swimmers during moderate-intensity training, the average daily energy expenditure measured by the doubly labeled water method, was calculated for nine female Japanese national team synchronized swimmers [four senior; mean (SD) 22.5 (1.0) years old, 52.2 (3.6) kg, and five junior; 17.6 (1.1) years old, 52.8 (2.3) kg]. Their total energy expenditure (TEE) was 11.5 (2.8) MJ · day⁻¹ [2738 (672) kcal · day⁻¹]. When compared with estimated energy requirements derived from “Recommended Dietary Allowances for the Japanese”, 12.1 (0.6) MJ · day⁻¹ [2897 (139) kcal · day⁻¹], there was no difference between mean actual and estimated energy requirements. However, there were considerable differences observed on an individual basis. Their energy intake, estimated from 7-day self-reported dietary records, was 8.9 (1.7) MJ · day⁻¹ [2128 (395) kcal · day⁻¹], which was significantly lower than their TEE (P < 0.05). Resting energy expenditure (REE), as determined by indirect calorimetry, was 5.2 (0.3) MJ · day⁻¹ [1247 (75) kcal · day⁻¹]. Their physical activity level (TEE/REE) was 2.18 (0.43). These results demonstrate that the TEE values of elite female synchronized swimmers are not dissimilar to those reported for athletes participating in other sports, especially competitive swimmers during moderate-intensity training.

Key words Female elite athletes · Total energy expenditure · Dietary food record · Doubly labeled water method

Introduction

It is essential to determine the energy requirements of not only general populations, but also athletes, to provide them with optimal nutritional information. Hence, there has been interest in measuring how much energy athletes expend during training (Dahlström et al. 1990; Davies et al. 1997; Edwards et al. 1993; Hawley and Williams 1991; Jang et al. 1987; Jones and Leitch 1993; Schulz et al. 1992; Sjödin et al. 1994; Trappe et al. 1997).

One athletic group of particular interest is swimmers. It has been reported that in swimmers, body cooling in water results in an increase in resting metabolism and in energy cost of exercise (Kollia et al. 1974; McArdle et al. 1984; Pendergast 1988). However, the collection of expired air that is required for measuring energy expenditure by indirect calorimetry is almost impossible during swimming. In addition, water immersion usually produces bradycardia (Irving 1963), which causes errors when estimating energy expenditure from heart rate monitoring using an equation of individual heart rate–energy cost. In relation to this fact, Oldridge et al. (1978) showed a significant greater decrease in exercise heart rates during facial immersion in synchronized swimmers compared with both speed and recreational swimmers. In addition, Takamoto and Mutoh (1983) pointed out that it is not possible to use heart-rate monitoring to estimate the training intensity of synchronized swimmers. To the best of our knowledge, there are few studies in which the daily energy expenditure of synchronized swimmers has been examined with accuracy.

The doubly labeled water (DLW) method for measuring total energy expenditure (TEE) is an accurate method for use in field studies (Montoye et al. 1996).
The technique has the advantage that TEE can be measured in free-living subjects with minimal interference, and requires only the periodic sampling of urine or saliva. Subjects can take part freely in their daily activities, even during an experimental period. The aim of this study was therefore to examine the average daily energy expenditure of synchronized swimmers during moderate-intensity training, using doubly labeled water. A second objective was to compare their energy expenditure values with the estimated energy requirement of “Recommended Dietary Allowances (RDA) for the Japanese” (Ministry of Health and Welfare of Japan 1994) and the estimated energy intake (EI) from 7-day dietary records.

Methods

Subjects

Nine Japanese female synchronized swimmers volunteered to participate in the study. Four of the synchronized swimmers were members of the Japan synchronized swimming A-team (senior group, international standing), and five were B-team (junior group, national standing). The subjects had no history of diabetes or any other metabolic disorder. The nature and purpose of the study was explained to each subject before they gave their consents to participate. The physical characteristics of the subjects are given in Table 1 (subject numbers 1–5: junior, subject numbers 6–9: senior).

The experiment was performed after the synchronized swimming competition at the Eighth World Swimming Championships (January 1998), during which time subjects engaged in their usual training regimen. Over the energy expenditure period, the senior group and junior group trained for a total of 1545 min (288 min·day⁻¹) and 1600 min (267 min·day⁻¹), respectively. There was no difference in training time between the senior and junior groups.

Measurement of TEE

The DLW procedure

TEE was measured over 6 days. Subjects were instructed to maintain their normal daily activities and eating patterns and to make no conscious attempt to lose or gain weight during the experimental period. On day 0 of the study, subjects were weighed in a fasted state before being asked to provide baseline urine and saliva samples. A single dose of 0.12 g·kg⁻¹ estimated total body water (TBW) of ²H₂O (99.8 atom %, Isotec, Miamisburg, Ohio, USA) and 2.5 g·kg⁻¹ estimated TBW of ¹⁵O₂ (10.0 atom %, Advanced Materials and Technology, New York, N.Y., USA) was given orally (Pulfrey and Jones 1996). TBW was estimated as being 60% of each individual’s body weight.

Subjects consumed no foods or fluids for 4 h after the isotope dosing. Saliva samples were collected at 3 and 4 h after the dose for measurement of TBW from ²H isotope dilution. The urine sample was collected on the morning of day 1 (24 h after administration of the isotope dose) and day 7. The urine samples taken on day 1 and day 7 were used to measure the elimination rates of ²H and ¹⁵O. All samples were stored by freezing at −5°C in airtight paraffin-wrapped plastic containers, and transported to the analytical facility on dry ice for isotopic analysis.

DLW laboratory analysis and calculation

The isotopic analysis was conducted using standard vacuum techniques, as described previously by Jones et al. (1988). For ²H enrichment determination, 6 mm OD Pyrex tubes containing 60 mg zinc were evacuated and flushed with nitrogen gas. A 2 µl capillary tube was filled with a physiological sample (urine or saliva) and added to the tubes before immersion in liquid nitrogen. The tubes were frozen with liquid nitrogen, evacuated, and sealed. Samples were reduced to hydrogen at 510°C for 30 min under 10⁻³ torr (where 1 torr = 133.322 N·m⁻²). For ¹⁵O, 1.5 ml of urine was added into a vacuum container and equilibrated with 1.5 ml SPDP CO₂ at 25°C for 48 h. ²H enrichment was analyzed using a 903D dual-inlet isotope ratio mass spectrometer (IRMS; VG Isogas, Cheshire, UK). The mass spectrometer was calibrated by using Vienna standard mean ocean water, 302B, and Greenland Ice Sheet Precipitation standards. All standards were obtained from the International Atomic Energy Agency. ¹⁵O was determined by SIRA 12 IRMS (VG Isogas, Cheshire, UK). All samples were run in duplicate or triplicate. The dilution space of each subject was obtained from saliva ²H enrichments using the following equation:

\[ N = \frac{W_0(\delta_0 - \delta_i)}/[18.02a(\delta_i - \delta_i)] \]  

(1)

where \( N \) (mol) is the dilution space, \( W \) (g) is the amount of tap water used to dilute the dose for analysis, \( a \) (g) is the amount of mixed dose given to the subject, \( \delta \) (‰) is the dilution factor for analysis, and \( \delta_0 \) (‰) is the enrichment of the dose (a), tap water (t), saliva sample after dosing (s), and saliva baseline (p).

TBW (mol) was calculated as \( N/1.041 \) (Racette et al. 1994).

Carbon dioxide production rates were calculated by using the following equation:

\[ r\text{CO}_2 = 0.4554 \times \text{TBW} \times (1.007\text{kb} - 1.041\text{kb}) \]  

(2)

where \( r\text{CO}_2 \) (mol·day⁻¹) is the rate of carbon dioxide production, TBW (mol) is the total body water, and \( \text{kb} \) and \( \text{kb} \) are the rates of ¹⁵O and ²H elimination (day⁻¹), respectively (Racette et al. 1994; Wolfe 1992). The DLW method is based on the assumption that after an initial oral dose of H₂¹⁵O, ²H is eliminated from the body as water, while ¹⁵O is lost both as water and as exhaled CO₂, so that the excess elimination rate of ¹⁵O relative to ²H, after adjusting for isotopic fractionation, is a measure of the rate of production of CO₂.

TEE (MJ·day⁻¹) was determined from \( r\text{CO}_2 \) (mol·day⁻¹) and food quotient (FQ), which is derived from food consumption data (Black et al. 1986), by using a modified Weir’s formula (1949):

\[ \text{TEE} = 22.4 \times [3.9 \times (r\text{CO}_2/FQ) + 1.1 \times (r\text{CO}_2)] \times 4.18/1000 \]  

(3)

Measurement of EI

To obtain EI and FQ over the experimental period, all foods and beverages consumed (other than water) were recorded on standard

<table>
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<tr>
<th>Subject</th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>BMI (kg·m⁻²)</th>
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