Energy Cost of Physical Activities in Healthy Elderly Women

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In recent studies, daily physical activity ratios (PARs) greater than the Food and Agriculture Organization/World Health Organization/United Nations University (FAO/WHO/UNU) reference value of 1.5 have been reported for elderly men and women. The purpose of this study was to investigate whether a high PAR in elderly subjects can be explained by a higher energy cost of physical activities (EEact). To this end, 12 elderly women aged 69 to 82 years, completed physical activity diaries during a 2-day stay in a respiration chamber. From these diaries, total daily energy expenditure (TEE) in the calorimeter was estimated (TEEfac) using FAO/WHO/UNU PARs for physical activities and measured resting metabolic rate (RMR). TEEfac was 7.0 ± 0.9 MJ/d (PAR, 1.35 ± 0.06). TEE was also measured in the chamber (TEEcal) and was 8.3 ± 1.3 MJ/d (PAR, 1.60 ± 0.16). TEEfac was 14.8% ± 8.1% lower than TEEcal. To investigate whether the underestimation of TEEcal was due to a higher EEact in the elderly women as compared with the FAO/WHO/UNU references, EEact of six specific activities ranging from sitting at rest to walking on a treadmill at self-chosen speed was measured with a ventilated-hood system. Individually measured PARs of the six activities were similar to FAO/WHO/UNU reference PARs. This study suggests that in elderly women a high TEEcal is not explained by EEact during nonstandardized physical activities performed at self-chosen speeds. Whether these results can be extrapolated to the free-living environment needs to be investigated further.

ACCORDING TO THE Food and Agriculture Organization/World Health Organization/United Nations University (FAO/WHO/UNU), the reference value for total daily energy expenditure (TEE) of elderly people is 1.5 times the resting metabolic rate (RMR).[1] Estimates of energy requirements of elderly people are often based on this reference value. Some studies confirmed a physical activity ratio ([PAR] TEE/RMR) of 1.5 in healthy elderly subjects.[2]

However, recent publications suggest that the daily PAR for healthy elderly people might be higher than the FAO/WHO/UNU reference value of 1.5. Values as high as 1.75 and 1.81 were recently reported for healthy elderly men and women, respectively.[3,4] Although the PAR is likely to be variable in elderly subjects due to different levels of physical activity,[2] the results of these studies suggest that the reference value of 1.5 might not be correct for certain groups of healthy elderly people.

A possible explanation for these high PARs might be a higher energy cost of physical activities (EEact) in elderly subjects as compared with younger age groups. This was already described by Durnin and Mikulicic,[5] who reported a higher energy expenditure during treadmill walking in elderly subjects as compared with young subjects. In a recent study, Voorrips et al[6] reported a higher energy expenditure during treadmill walking in elderly women as compared with middle-aged subjects.

A high TEE in healthy elderly people due to a higher EEact has important implications for nutritional requirements, guidelines, and recommendations. The food and energy intake of elderly subjects should be high enough to prevent weight loss and micronutrient deficiencies but should also preclude obesity. Therefore, more data on the energy expenditure of the healthy elderly are indispensable.

The purpose of this study was to investigate whether a higher PAR in elderly subjects, as compared with the FAO/WHO/UNU reference value of 1.5, could be explained by a higher EEact.

SUBJECTS AND METHODS

Subjects

Twelve women were recruited from a study population of 120 elderly men and women who had participated in a study on body composition and energy expenditure. All subjects were apparently healthy and living in the surrounding area of Wageningen. One woman lived in a residential home, and the other women were noninstitutionalized. Health status was evaluated by means of a medical questionnaire checked by a physician. Subjects who were taking medication that could influence energy expenditure, eg, β-blockers, and heavy smokers were excluded from the study. Subjects with serious diseases or disabilities that could interfere with the performance of physical activities during the study were excluded. Except for one woman (who smoked three to four cigarettes per day), all subjects were nonsmokers. The physical activity scores of the women, as determined by a questionnaire,[7] suggested that the subjects were not extremely physically active. However, a large variation in the free-living physical activity level between subjects was apparent. Some characteristics of the women are listed in Table 1. All subjects were familiar with most of the methods used in this study. Other methods were thoroughly explained. All subjects provided written informed consent. The study protocol was approved by the Ethics Committee of the Department of Human Nutrition of the Wageningen Agricultural University.

Study Protocol

TEE was measured on 2 consecutive days in a respiration chamber. During their stay in the chamber, subjects completed a physical activity diary. One to 4 days after these measurements, body composition, RMR, and EEact during various activities were determined. The mean time between measurements in the respiration chamber and measurements of RMR and EEact was 3 ± 2 days.

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Table 1. Characteristics of the Subjects (N = 12)

Characteristic	Mean ± SD
Age (yr)	74 ± 3
Body weight (kg)	65.4 ± 11.6
Height (m)	1.60 ± 0.05
Body mass index (kg/m^2)	25.6 ± 4.7
Body fat (%)	37.9 ± 9.6
Fat-free mass (kg)	39.6 ± 3.5

TEE

TEE was measured using whole-body indirect calorimetry (TEEcal).[8] Air was drawn from each chamber using an air-suction pump, and the flow was measured by a dry gas meter. Air speed was 31 to 53 L/min depending on body weight of the subject. Dry gas meters were calibrated before and after each calorimetric session using a Blakeslee piston pump with mercury seals. Twenty-four-hour composite air samples of room air (in duplicate) and fresh outside air were collected in glass tubes containing mercury and analyzed volumetrically for O_2 and CO_2 with a Sonden apparatus.[9] At the start and end of the measurement, room air samples were drawn and analyzed to correct for changes in O_2 and CO_2 concentration of the calorimeter over 24 hours. Recoveries of combusted alcohol were 100.2% ± 0.8% for oxygen and 98.7% ± 0.8% for carbon dioxide. Weir's equation was used to calculate TEEcal from the amount of consumed O_2 and produced CO_2 over 24 hours.[10]

TEEcal was measured on 2 consecutive days. Subjects entered the calorimeter in the evening (11:00 PM), 8 to 9 hours before the start of the measurements (7:30 AM the next morning). Immediately at the end of the first 24-hour period, the measurement of the following 24-hour period started. The ambient temperature was set at 21° to 22°C for daytime and at 18° to 19°C during the night, but was adjusted when the subject felt uncomfortable. Mean temperature over 24 hours was 20.7° ± 1.0°C, and relative humidity was between 60% and 70%. The room was fully equipped with a small kitchen and water-tap, writing desk, television, radio, telephone, bed, toilet chair, comfortable chair, and cycle ergometer (type RH; Lode, Groningen, The Netherlands). Two airlocks served as an inlet for food and an outlet for feces and urine. The three meals, snacks, and drinks consumed during the stay in the calorimeter were provided, and the amount was based on the results of a dietary history.[11] Subjects kept their regular meal pattern and consumed similar foodstuffs as in the free-living situation. The activity pattern in the room was partly standardized, which consisted of 8 hours of lying down in bed and cycling five times for 15 minutes on a cycle ergometer (20W at 40 rpm). Two subjects cycled two to three times per day. The remaining time was spent engaged in sitting and standing activities including dressing, preparing meals, making tea or coffee, and washing dishes, which simulate light housekeeping activities. Performance of strenuous physical exercise was not allowed.

Physical Activity Diary

Physical activity diaries were used to estimate daily energy expenditure (TEEfac) during the stay in the respiration chamber and to compare this value with TEEcal. Daily activities were grouped into seven categories of energy expenditure to facilitate registration of activities by 5-minute intervals. The categories were as follows: (1) lying down, (2) sitting quietly or very light sitting activity, (3) light to moderate sitting activity, (4) standing or light standing activity, (5) standing activity or walking around, (6) walking activity or cycling, and (7) recreational activity.[12] Use of the diaries was extensively explained to the subjects. Subjects with difficulties understanding the method were asked to complete a test diary for 1 day at home before TEEcal measurements. This diary was discussed afterward to make the subjects familiar with the method. On the first page of each diary, examples of activities of each category were given to facilitate classification of daily activities. Activities difficult to classify were noted by the subjects on a separate page in the diary and discussed afterward with the investigators. TEEfac was calculated by multiplying the sum of the minutes spent on each activity category with the PAR of each activity category and with measured RMR values. For this purpose, both FAO/WHO/UNU[1] factors and measured PARs derived from actual EEact measurements during specific activities were used (to follow). The PAR of the highest activity category, sports, could not be measured. For this category, the FAO/WHO/UNU factor was used only.

RMR and EEact

Using indirect calorimetry, RMR and EEact were measured with an open-circuit, ventilated-hood system to calculate PAR factors (EEact/RMR) for each individual. Through the hood, fresh filtered outside air was drawn by a pump (SCL210; Ocean, Dieren, The Netherlands). Airflow was measured by a thermal mass flow meter (5812N; Brooks, Veenendaal, The Netherlands) and maintained by a control valve (Brooks 5837). Gas analyses were performed with an infrared CO_2 analyzer (1410; Servomex, Zoetermeer, The Netherlands) and a paramagnetic O_2 analyzer (Servomex 1100A). The analyzers were calibrated using dried standard gas mixtures and dried filtered fresh outside air. Before all metabolic measurements, the span of the oxygen analyzer was controlled. Flow rate during RMR measurement was 40 L/min, during sitting and standing activities 80 L/min, and during bicycling and walking 120 L/min. Flow rate and carbon dioxide and oxygen concentrations were integrated over 1-minute intervals. Energy expenditure was calculated using Weir's equation.[10] On a biweekly basis, alcohol combustion testing at the three different flow rates was performed to test the system. Reproducibility of ventilated-hood measurements was determined by six alcohol combustion tests for each ventilated hood, performed on separate days within a period of 2 weeks. Day-to-day coefficients of variation were 2.1% for O_2 consumption, 1.9% for CO_2 production, and 1.9% for energy expenditure.

RMR was measured after an overnight fast. Subjects were brought by car to the laboratory at 8:00 AM. They were instructed to avoid intensive physical activity on the day and morning before the measurements. During the measurements, they were in a semisupine position on a hospital bed in a thermoneutral room (temperature, 22° ± 1°C) watching video movies. RMR was measured continuously for 60 minutes, and the results of the last 45 minutes were used. All subjects were familiar with the ventilated-hood measurements.

After measurement of RMR, subjects were offered a small breakfast consisting of a cup of tea (with sugar) and one cracker with margarine and jam (~500 kJ). Then energy expenditures during six activities were measured: (1) sitting while watching video films; (2) sitting with light arm movements, ie, at a table completing a jigsaw puzzle; (3) standing with light arm movements, ie, at a table completing a jigsaw puzzle; (4) standing with heavy arm movements, ie, moving wooden blocks (350 g) from one side of the table to the other side, thereby passing the blocks from hand to hand at eye level; (5) bicycling on a cycling ergometer with a load of 20W and a pedaling frequency of 40 rpm; and (6) walking on a treadmill (Enraf Nonius, Delft, The Netherlands). To approximate the normal daily situation, all activities were performed at a self-chosen speed or frequency, except for cycling activity.

The walking activity was first practiced for 5 minutes without using the ventilated hood to familiarize the subjects with walking on a treadmill and to adjust to a normal walking speed for the subject. Walking speed ranged from 0.6 to 4.5 km/h, with a mean value of 2.2 ± 1.0. Each activity was performed for 10 to 12 minutes. The mean energy expenditure of the last 5 minutes of each activity was used. Mean room temperature during the measurements was 20°C.

Body Composition and Anthropometry

All anthropometric measurements were made after voiding, with the subjects wearing a swimming suit or underwear. Body weight was measured to the nearest 0.05 kg using a digital scale (ED-60-T; Berkel, Rotterdam, The Netherlands). Height was measured to the nearest 0.001 m using a wall-mounted stadiometer. Body mass index was calculated as weight in kilograms divided by height in meters squared.

Body composition was calculated from total body water measured by isotope dilution. An exactly weighed amount of deuterium oxide (~14 to 15 g) was given orally to the subjects. After a dilution time of 3 hours in which subjects refrained from eating and drinking, a venous blood sample was drawn. After sublimation of the plasma, deuterium concentration was determined in the sublimate by infrared analysis.[13] Total body water was estimated from the deuterium oxide concentration in the plasma and corrected for a 5% overestimation of the dilution space.[14] Fat-free mass was calculated as total body water divided by 0.732, assuming a hydration coefficient of the fat-free mass of 0.732.[15] Body fat was calculated as body weight minus fat-free mass.

Statistical Methods

Data were analyzed using the statistical program SAS (SAS Institute, Cary, NC). Differences between TEEcal and TEEfac were tested with paired Student's t tests. Correlations between variables are Pearson's product-moment correlations. Results are presented as the mean ± SD. Two-sided P values less than .05 were considered significant.

RESULTS

Mean age and anthropometric characteristics of the 12 women are listed in Table 1. Table 2 lists results for TEE as measured in the respiration chamber. The mean PAR of elderly women in the respiration chamber was 1.60 ± 0.16. TEEfac, derived from activity diaries completed in the calorimeter, showed a PAR of 1.35 ± 0.06, which underestimated TEEcal by 14.8% ± 8.1% when FAO/WHO/UNU PARs were used. The difference between TEEfac and TEEcal was positively correlated with TEEcal (r = .78 and P = .003 using FAO/WHO/UNU PAR factors). Thus, the deviation from TEEcal was larger when energy expenditure in the chamber was higher, ie, when more physical activities were performed in the chamber. The prediction error was not related to body weight (r = .24, P = .5), percent body fat (r = .06, P = .8), RMR (r = .26, P = .4), or age (r = .43, P = .16). The physical activity pattern, as reported in physical activity diaries by the elderly women, is listed in Table 3.

Table 2. Comparison of TEE and Derived PARs During the Calorimetric Sessions of Elderly Women Using Indirect Calorimetry and FAO/WHO/UNU PAR Factors for Physical Activities in the Factorial Method

Method	Mean ± SD
Indirect calorimetry	
TEEcal (kJ/d)	8,299 ± 1,294
PAR	1.60 ± 0.16
Factorial method using FAO/WHO/UNU factors and RMR	
TEEfac (kJ/d)	7,015 ± 857
PAR	1.35 ± 0.06
Difference from measured TEE (%)	14.8 ± 8.1*

*P < .001: difference = (TEEcal − TEEfac/TEEcal) × 100%.

Table 3. Activity Pattern in the Respiration Chamber According to the Physical Activity Diary

Activity Category	Minutes per Day (mean ± SD)
Lying	525 ± 36
Sitting quietly or very light sitting activity	694 ± 84
Light to moderate sitting activity	0 ± 0
Standing or light standing activity	127 ± 92
Standing activity or walking around	19 ± 26
Walking activity or cycling	66 ± 21
Recreational activity	2 ± 5

The underestimation of TEEcal using the factorial method might be caused by use of the FAO/WHO/UNU PARs. This was evaluated further by comparing PARs derived from measurements of energy expenditure at rest and during six specific physical activities with PARs for specific activities according to the FAO/WHO/UNU (Table 4). Except for the walking PAR, other values derived from actual energy expenditure measurements were less than FAO/WHO/UNU PARs. The PAR of the walking activity was not different from the FAO/WHO/UNU reference value. Energy expenditure during sitting with arm activity was slightly higher as compared with the reference value.

Estimated TEEfac using these individually measured PARs was 6,442 ± 707 kJ/d (PAR, 1.24 ± 0.06), which is 21.6% ± 7.8% (P < .0001) lower as compared with TEEcal.

DISCUSSION

In the present study, TEE of healthy elderly women was measured in a respiration chamber. Physical activity diaries, in combination with FAO/WHO/UNU PARs and RMR, underestimated TEE as measured in a respiration chamber. This underestimation could not be explained by higher EEact in these elderly women as compared with FAO/WHO/UNU reference PARs.

Table 4. EEact and PAR at Rest and During Six Activities of 12 Elderly Women

	Measured (mean ± SD)		FAO/WHO/UNU Reference Value
Activity Category	EEact (kJ/min)	PAR*	PAR
Resting	3.59 ± 0.34	—	1.0
Sitting quietly	4.29 ± 0.37	1.20 ± 0.06†	1.3
Moderate sitting activity	5.62 ± 0.63	1.57 ± 0.11‡	1.5
Light standing activity	5.64 ± 0.75	1.57 ± 0.13†	1.8
Standing activity	7.47 ± 1.09	2.07 ± 0.20†	2.7
Cycling	10.61 ± 1.12	2.96 ± 0.30†	3.5
Walking	12.54 ± 2.53	3.49 ± 0.62	3.5

*PAR = EEact/RMR.
†P = .0001, ‡P = .06: v FAO/WHO/UNU PARs.

The study population consisted of 12 healthy elderly women, most of whom were living independently. Age, body weight, height, and body mass index were comparable to values for elderly women who participated in an earlier study at our department.[16] In the previous study, mean values for these variables were 70 ± 5 years, 68 ± 10 kg, 1.62 ± 0.06 m, and 26.1 ± 3.6, respectively. Body weight was also comparable to that of elderly women of the same age living in The Netherlands: 69.8 kg for women between ages 60 and 69 years and 67.1 kg for women ≥ 70 years.[17]

The PAR for elderly women in the respiration chamber was 1.60 ± 0.16. In a recent study, the PAR for a group of younger women (mean age, 28 years) in a respiration chamber was found to be 1.48,[18] which is considerably less than the PAR found in the present study group. In this study, the same equipment was used and subjects followed the same standardized activity pattern. Therefore, differences are not likely to be caused by differences in physical activity pattern. The data reported by Vaughan et al[19] suggest a PAR of 1.39 in elderly subjects and 1.23 in younger subjects in a respiration chamber. Furthermore, in that study the PAR of the younger group was less than the PAR of older subjects, despite the same level of spontaneous physical activity (which was measured by radar units) of the two age groups. The PAR of elderly subjects in the study reported by Vaughan et al[19] is less than in the present study, which may be due to the fact that subjects in that study did not perform any strenuous activity (like bicycling). These results suggest that even with standardized activity patterns or the same level of physical activity, the PAR in elderly subjects might be higher than in younger subjects. In contrast, a study reported by Pannemans et al[20] showed similar mean PARs (1.58) during 24-hour energy expenditure measurements in young and elderly men performing nearly identical activity protocols. However, in the latter investigation the intensity of the stepping exercise was less in elderly men versus younger men.

Our elderly subjects completed a physical activity diary while in the respiration chamber. When using FAO/WHO/UNU PAR factors[1,12] and measured RMR for calculating TEEfac, TEEcal was underestimated by 14.8% ± 8.1% at group level, with individual errors between −23.4% and +7.3%. Two other studies[21,22] comparing a factorial method with continuous respirometry in young men and women reported a high agreement between the two methods (within 1% to 2% for group results). Individual differences in these studies were between −11.6% and +15.1%[21] and −17% and +25%.[22]

The apparent underestimation of TEEcal in the group of elderly women by the factorial method could have been caused by several factors. First, TEEcal may have been too high due to measurement errors or stress of the subjects. However, respiration equipment was calibrated regularly with alcohol burning during 24 hours, and recoveries were 100.2% and 98.7% for O_2 and CO_2, respectively. Second, in the present study, the within-person, day-to-day variation coefficient for TEE was 3.3%, which is comparable to values from other studies (4.6%[21] and 2.6%[23]). No significant day effect ($P = .93$) was found between the two measurement days, and all subjects reported feeling at ease at the end of the first 9 hours, after which actual measurements started. It would therefore appear unlikely that these factors contributed significantly to the large discrepancy observed between TEEcal and TEEfac.

Furthermore, errors may have been made in recording physical activities in the diary. However, this method was extensively explained to all subjects and all were able to complete the activity diary independently. Any problems were discussed immediately with the investigators. There is no reason to assume that this group of highly motivated women were less capable of completing the activity diaries than younger age groups. However, a recording bias cannot be excluded in the present study.

An earlier study performed in 80 elderly women at our department showed that the within-person, day-to-day variation coefficient for RMR was 6.0%.[24] Therefore, it seems improbable that the use of a single RMR measurement could have been the cause of the large difference observed between predicted and measured TEE, specifically since the elderly subjects were familiar with the ventilated-hood equipment and the procedures used to measure RMR.

Another explanation for the discrepancy between TEEcal and TEEfac might be a large difference between RMR (as measured by the ventilated-hood system) and sleeping metabolic rate ([SMR] as measured in the respiration chamber). SMR could not be measured in the present study, but a previous study in which the same equipment was used showed good agreement between RMR (4.0 ± 0.4 kJ/min) and SMR (3.8 ± 0.4) in young women.[18] Therefore, the difference between TEEcal and TEEfac seems unlikely to be caused by large differences between RMR and SMR.

The FAO/WHO/UNU PARs used to calculate TEEfac are based on studies in younger women and may have been too low for elderly subjects. Two studies have reported a higher energy expenditure for elderly people as compared with younger subjects during standardized walking activity on a treadmill, even after adjustment for body weight.[5,6] In the first study, energy expenditure during treadmill walking at two different fixed speeds was compared between young and elderly subjects. Walking activity was standardized at two speed levels: 5.9 and 6.9 km/h. Energy expenditure of elderly subjects was higher, even after adjustment for differences in body weight between the two age groups.[5] The second study showed a higher energy expenditure during treadmill walking in elderly women as compared with middle-aged women.[6] In the latter study, a fixed pace was used (3 km/h). In the present study, the PAR for walking was not different from the FAO/WHO/UNU value of 3.5. A large difference between the two above-mentioned studies and the present study is the speed of walking. In the present study, the speed of the treadmill was individually adjusted to make energy expenditure during walking comparable to the free-living situation. Although all women were physically healthy and treadmill walking was practiced until the subjects felt comfortable, the mean walking speed in our study was slower, 2.2 ± 1.0 km/h. Durnin and Mikulicic[5] have suggested that walking, which requires use of large muscle masses, movement of many joints, and readjustment of posture, may be less regulated in elderly subjects, therefore increasing their energy expenditure. Furthermore, since body weight increases and fat-free mass decreases with increasing age, a higher body weight must be moved with relatively less muscle mass, thereby possibly increasing energy expenditure. At a speed higher than the usual pace of elderly subjects, these effects might be even stronger. This is the most probable explanation for the high energy expenditure of elderly subjects in studies reported by Durnin and Mikulicic[5] and Voorrips et al.[6] Results of the present study suggest that when activities are performed at a normal, self-chosen pace (ie, with a lower intensity than in younger subjects[25]), PARs of elderly subjects are equal to FAO/WHO/UNU reference values. This was also reported by Didier et al,[26] in whose study elderly subjects needed a longer time to get up from and lay down on the floor or a bed as compared with young subjects, but energy expenditure was the same.

Another reason for the discrepancy between TEEcal and TEEfac might be the food intake of the subjects. Overfeeding the subjects during the stay in the respiration chamber may have led to an increased energy expenditure.[8] Food intake in the chamber was based on the results of a dietary history.[11] The dietary history indicated a mean energy intake of 7.2 ± 1.5 MJ/d. TEE measurements in the present study indicated a TEE of 8.3 ± 1.3 MJ/d. Although actual energy intake during the stay in the respiration chamber was not measured, these results suggest that the subjects were probably underfed (by ~12%) while in the respiration chamber. Therefore, the difference between TEEcal and TEEfac seems unlikely to be caused by overfeeding the subjects. In several studies, the diet-induced thermogenesis of elderly subjects is reported to be the same as or less than that of younger subjects. Therefore, an unexpected high diet-induced thermogenesis seems unlikely to account for the difference between TEEcal and TEEfac. Furthermore, assuming that the diet-induced thermogenesis of the elderly women was 20% of TEE (or 1,630 kJ in the present study) instead of the normal 10% of TEE (or 830 kJ), this difference of 830 kJ cannot explain the difference between TEEcal and TEEfac (which was 1,284 kJ).

As previously reported, energy requirements of elderly people are likely to vary greatly due to large variations in physical activity levels.[2] Furthermore, recent studies suggest that the PAR might be greater than 1.5 for healthy elderly subjects.[3,4] The estimation of energy requirements seems more complex than using a simple constant and multiplying this by (estimated) RMR. As a consequence, the FAO/WHO/UNU reference value of 1.5 can only be used to make a rough estimate of energy requirements.

The present study demonstrated that energy expenditure during nonstandardized physical activities in healthy elderly women was not higher as compared with FAO/WHO/UNU reference values for physical activities. Thus, the difference between measured TEE (using a respiration chamber) and estimated TEE (using a factorial method) could not be explained by higher EEact during nonstandardized physical activities in elderly people. The data imply that physical activity in the respiration chamber was probably underrecorded by the elderly subjects, causing an underestimated TEE from the factorial method. Whether these results can be extrapolated to the free-living environment needs to be evaluated further.

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