Original Article

Evaluation of the Factorial Method for Determination of Energy Expenditure in 16 Young Adult Women Living in China*

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Abstract

Objective The present study aimed to evaluate the accuracy of the factorial method for estimating energy needs in individuals living in China.

Methods Sixteen healthy female adults aged 22.1±1.2 years with a body mass index (kg/m^2) of 20.4±1.7 were selected as subjects. In free-living conditions, energy expenditure (EE) was determined by using the factorial method. At the same time, the doubly labeled water method (DLW) was also used to measure energy expenditure of the subjects and served as the criterion method. EE predicted by the factorial method ($EE_{factorial}$) was compared with the simultaneous measurement of EE by the validated DLW method (EE_{DLW}).

Results There was excellent agreement between $EE_{factorial}$ (7.46±0.59 MJ/d) and EE_{DLW} (7.64 ± 0.49 MJ/d), with a difference of -2.6±4.9% (-0.18±0.36 MJ/d). No significant differences were found between the two methods. $EE_{factorial}$ was highly correlated with EE_{DLW} (r=0.795, P<0.001) and a good agreement for individuals was found by using the Bland and Altman test.

Conclusion The factorial method gives satisfactory estimates of EE for both groups and individuals living in China.

Key words: Energy expenditure; Chinese adults; Factorial method; Doubly labeled water

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INTRODUCTION

An accurate estimation of an individual's daily energy need is important in nutritional support and diet design. Many methods have been developed, including factorial, heart rate, questionnaire, intake-balance and doubly labeled water (DLW) measures in free-living situations. Among them, the DLW method is commonly considered the golden standard against which other field methods should be compared.

Although the DLW method is considered a criterion method for estimating energy expenditure (EE) in free-living persons, the cost of isotopes and analyses and the requirement for an isotope ratio mass spectrometer prohibit it from being widely used in studies of large populations, especially in developing countries. Currently, most developing and transitional countries (including China) still use

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the factorial method recommended by the 1985 FAO/WHO/UNU report for estimating individual and population needs[1-2]. This report provides guidelines for predicting EE in individuals as well as in groups and bases its predictions on a factorial technique. By using measured or predicted values for basal metabolic rate (BMR) and level of physical activity (PAL), daily energy requirement is expressed as a multiple of BMR.

Although this method plays a central role in assessing energy requirements, concerns remain about its accuracy. Some validation studies of the factorial method against a criterion method such as DLW for determining EE have been performed in the past few years, but the results are variable. Some studies demonstrated that the factorial method underestimated EE in free-living conditions, while others obtained the opposite results. For example, in two direct comparisons of factorial energy requirement estimates with DLW, one study confirmed that the factorial method underestimated energy needs[3], while the other found no difference between the methods in an elderly population with a mean age of 70 years[4]. A comparison of factorial energy requirement estimates with whole-body indirect calorimetry measurements in Canadian adults showed that the FAO/WHO/UNU (1985) procedures may overestimate daily energy needs, particularly in sedentary individuals[5].

Moreover, these results were mostly derived from studies in Western Europe and North America. To date, however, few studies have evaluated the accuracy of the factorial method for estimating energy needs for individuals living in Asia. Within China, there are minimal available data on energy needs by using the factorial method. There is an urgent need for more TEE and measured BMR studies, coupled with time-motion studies from developing countries that cover prevailing and changing life styles, which is one of the suggested areas where further research is needed, as proposed by a 2001 expert consultation[6].

Our study aimed to use the factorial method to predict EE in free-living Chinese adults and to assess this method by comparing predicted EE ($EE_{factorial}$) with simultaneous measurements of EE with the validated DLW method (EE_{DLW}). We also evaluated the accuracy of the factorial method for estimating energy needs in individuals living in China.

MATERIALS AND METHODS

The study protocol was approved by the Human Studies Ethics Committee of the Institute of Nutrition and Food Safety, Chinese Center for Disease Control and Prevention.

Subjects

The study was conducted at the Bethune Military Medical College, which is in the city of Shi-jia Zhuang, the capital city of Hebei Province in north China, approximately 300 km south to Beijing. The volunteers were recruited from the students of the college. Through questionnaire and normal medical evaluations, 16 healthy female students were selected as the subjects for this study. All subjects were 20-25 years old, healthy, none had a history of diabetes or any other metabolic disorder and none had their menstrual periods during the study. They all had normal body weights (body mass index, kg/m^2 of 18.5-24 kg/m^2) and had maintained stable weights for several months before the study. The nature and purpose of the study were explained to each subject and written informed consents were obtained.

Experimental Protocol

The investigation was conducted over a 16-d period. During the study, the participants were required to reside at the hostel of the college and all food consumed by them was provided by the investigators. To maintain energy expenditure relatively constant throughout the study, subjects were required to follow sedentary or light-activity lifestyles.

The first 2 days was the adaptation period when the subjects moved into the hostel to get used to the environment. The test period was 14 d. During the 14-d study, the subjects ate their three meals under supervision of the research staff and energy intakes were adjusted during the first few days until their weight stabilized. The provided diets mimicked a typical Chinese diet; therefore, approximately 55%-65% of the energy was derived from carbohydrates and 20%-30% from fat, with a food quotient of 0.88. Anthropometric, BMR, PAL, and EE data of the subjects were collected as described below.

Anthropometric Measurements

Anthropometric measurements (including weight and height) were obtained daily. After an overnight fast, weight was measured to 0.01 kg by using digital electronic balance (HW100KGL, Japan) in the morning with the subjects wearing minimal clothing, and height was measured to 0.1 cm with a stadiometer while subjects stood barefoot.

Body composition was determined using a four-terminal bioelectric impedance analyzer (101, RJL Systems, USA) as described by Lukaski et al.[7] and fat-free mass (FFM) was calculated from the equation proposed by the Chinese Nutrition Society[8].

Measurement of Daily Energy Expenditure

BMR BMR was measured from gaseous exchange via the recently developed K4b^2 portable metabolic system (Cosmed, S.R.L., Rome, Italy) as detailed elsewhere[9]. In this procedure, after an overnight fast of 10-12 h, the subjects were gently awakened from sleeping and lying quietly in bed. They were instructed to relax and avoid hyperventilation, fidgeting and sleeping during measurements. Rates of oxygen consumption (VO_2) and carbon dioxide production (VCO_2) were measured over 15 min using K4b^2 equipment. Data from the first 5 min were excluded and the remaining data were averaged. From these data, BMR was calculated by using the Weir equation[10]. Calibration of the Cosmed K4b^2 was conducted prior to each test following the manufacturer's guidelines.

PAL To evaluate PAL of the participants, a 24-h activity record was administered to the subjects. Habitual activities carried out during the entire 14-d study were recorded by each subject on a time sheet and each record was checked daily for completeness and clarity by the investigators. For coding the data, the main daily activities performed by the subjects were grouped into eight main categories (Table 1). Each category was assigned a physical activity ratio (PAR), which reflects the energy cost as a multiple of BMR, as described in the FAO/WHO/UNU report[6]. PAL was calculated from time spent on activities in each category and their PAR values as described in the FAO/WHO/UNU report[6].

PAL = Σ time allocation for each daily activity (h) × energy cost (PAR)/24 (h)

Table 1. Activity Categories used for Estimating Energy Expenditure from Time-Allocation Data

Main Daily Activities	Energy Cost (PAR)*	Selected Examples
Sleeping	1.0	
Resting	1.2	sitting or lying quietly
Personal Care	2.3	dressing, showering, washing hands/face
Eating	1.5	
General Household Work	2.8	sweeping, washing clothes, bed making
Attending Classes	1.5	writing，reading
Walking at Varying Paces without a Load	3.2	
Light Leisure Activities	1.4	watching TV, chatting

Note. *PAR = physical activity ratio, energy cost of the activity/basal metabolic rate.

Factorial Method Energy expenditure was predicted from the factorial method ($EE_{factorial}$) by multiplying recorded PAL by the mean BMR of each subject. $EE_{factorial}$ = BMR×PAL

Doubly Labeled Water Method The EE over the 14-d study was determined by the multi-point DLW method[11]. Briefly, on the first day of the experiment, the subjects got up at 6:00 in the morning. After providing a baseline urine sample, each participant ingested a known quantity of DLW dose (Huayi Isotope Co., Changshu, China) to provide 0.15 g $H_2{}^{18}O$/kg body weight and 0.25 g ^2H_2O/kg body weight). Urine samples were collected five times on day 1, once before administration of the DLW and then 2, 4, 6, and 8 h after administration of the dose. In the subsequent days of the protocol, urine samples were collected once a day. Urine samples were stored in several 5 mL sealed sample tubes at -20 °C. Isotopic enrichment of urine samples was analyzed at the Laboratory for Stable Isotope Geochemistry (Geological and Geophysical Research Institute, Chinese Academy of Sciences) with a MAT-252 and MAT-253 (Thermo Finnigan, USA) gas-isotope-ratio mass spectrometer for deuterium and ^{18}O, respectively. Standards prepared by the investigators, but unknown to the commercial laboratory, were used to monitor the subcontractor's performance. Energy expenditures (EE_{DLW}) were calculated by a multipoint calculation technique.

Statistical Analysis

Data were analyzed by SPSS software (version 10.0; SPSS, Inc, Chicago, USA). Descriptive data are presented as mean±SD. The Student's t-test for independent variables was used to ascertain significant differences between measurements. For all measurements, results were considered statistically significant at $P<0.05$. Single correlations were calculated between different variables. Agreement between the two methods was also measured using the statistical approach outlined by Bland and Altman[12].

RESULTS

The physical characteristics of the participants are presented in Table 2. Sixteen healthy females aged 22.1 ± 1.2 years were recruited for this study. The mean body mass index value was 20.4±1.7. Body weights and compositions (expressed as fat-free mass) were monitored daily and the results are shown in Table 2.

Table 2. Physical Characteristics of the Subjects ($\bar{x} \pm s$)

Item	Values (*n* = 16)
Age (year)	20-24 (22.1 ± 1.2)*
Height (cm)	159.2-169.1 163.8 ± 3.2
BMI (kg/m^2)	18.6-23.1 (20.4 ± 1.7)*
Body Weight (kg)	47.2-63.0 (54.5 ± 4.7)*
Fat-Free Mass (kg)	38.8-45.3 (41.3 ± 2.3)*

Note. *Numbers in parentheses are 95% CIs.

Measured BMR (EE_{BMR}) and comparisons between EE_{DLW} and $EE_{factorial}$ are shown in Table 3. EE_{BMR} ranged from 4.03 to 5.85 MJ/d (4.71±0.55 MJ/d). Estimates of daily energy expenditure based on $EE_{factorial}$ were lower than those derived by EE_{DLW} by -2.6±4.9% (-0.18±0.36 MJ/d) as presented in Table 3. This difference was not significantly different from zero.

Figure 1 shows the relation between the energy expenditures obtained from the two methods. $EE_{factorial}$ was highly correlated with EE_{DLW} (r=0.795, $P<0.001$).

Table 3. Basal Metabolic Rate (EE_{BMR}) and Energy Expenditure (EE) as Determined by the Doubly Labeled Water Method (EE_{DLW}) and Factorial Method ($EE_{factorial}$) ($\bar{x} \pm s$)

Item	Values (*n* = 16)	Difference
	(MJ/d)	(MJ/d)
EE_{BMR}	4.03-5.85	—
	(4.71 ± 0.55)*	—
EE_{DLW}	6.71-8.35	—
	(7.64 ± 0.49)*	—
$EE_{factorial}$	6.32-8.43	t=0.5120, P=0.6163#
	(7.46 ± 0.59)*	-0.18 ± 0.36

Note. *Numbers in parentheses are 95% CIs. The difference between #$EE_{factorial}$ and EE_{DLW} was not significantly different from zero. A positive value indicates an overestimation of EE and a negative value indicates an underestimation of EE.

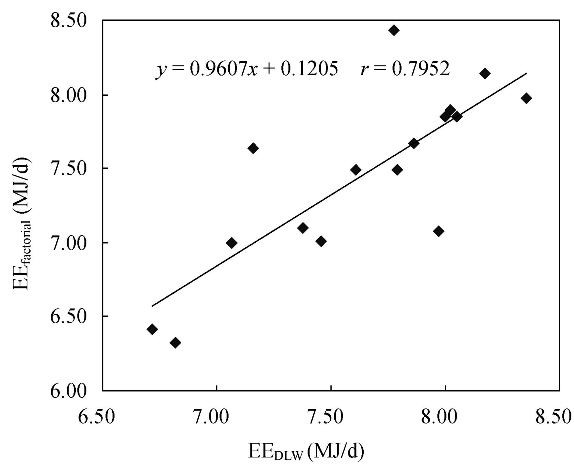

Figure 1. Energy expenditure from the doubly labeled water method (EE_{DLW}) versus predicted EE from the factorial method ($EE_{factorial}$).

Figure 2 compares the two methods by using the statistical method developed by Bland and Altman. For each subject, the difference between the factorial and DLW estimates was plotted against the mean of the two methods. All points fell within 2 SDs of the mean difference and the difference scores (expressed as mean and 95% CI) were centered closely around zero, showing that the factorial method agreed closely with the DLW method.

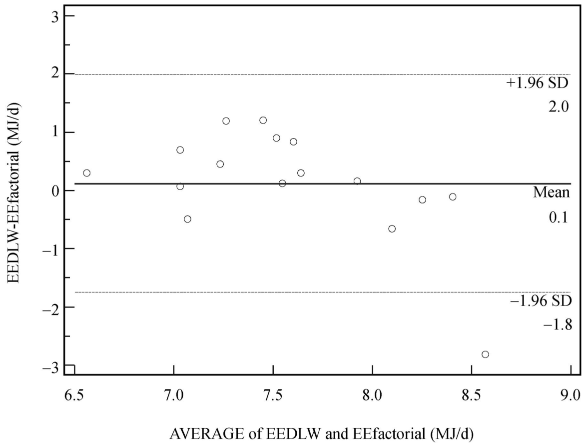

Figure 2. Difference between energy expenditures measured by the doubly labeled water method (EE_{DLW}) and by the factorial method ($EE_{factorial}$) plotted against the mean of the two measurements according to Bland and Altman. The limits of agreement were plotted, which equal 2 SDs of the difference above and below zero.

DISCUSSION

The factorial method is the most often used method for estimating EE in China. However, there has been little validation of this method. The present study is the first to assess the accuracy of the factorial method for predicting EE in free-living individuals in China. The DLW method was used to calculate the free-living EE and served as the criterion method for this investigation. The small difference between mean EE_{DLW} and $EE_{factorial}$ (Table 3) in this study supports the advantage of the factorial method for estimating EE in a population. Furthermore, the good individual agreement between the two methods (Figure 2) indicates that the factorial method may be useful for estimating free-living EE in individuals in China.

Our generally good agreement between predicted and measured 24-h EE is not unexpected because variations in the factorial method were not well controlled in the present study. The bias and variability associated with the factorial method are related to several variables including: (1) the BMR measurement, (2) the activity recordings, and (3) determination of the energy cost of the various activities. Precise measurement of the BMR value is required, not only because BMR is the major determinant of 24-h EE, but also because the energy costs of the various activities are related to BMR; a 10% misdetermination of BMR results in a 10% misdetermination of EE. In the present study, we measured the BMR of individuals to reduce individual errors from incorrect predictions from published equations. The equipment used for measuring BMR was a Cosmed $K4b^2$ portable metabolic system, which has been shown to provide similar values of oxygen uptake, carbon dioxide production, minute ventilation and respiratory exchange ratio as those obtained by the Douglas bag method or a metabolic unit[13-14].

On the other hand, the factorial method is liable to produce errors from faulty information on the time spent in various activities and the energy cost of each activity. Because activities vary greatly from day to day, a person's PAL can be more accurately evaluated from a meticulous activity log maintained over a period of a week or more. In this study, a 24-h activity record was administered to the subjects and habitual activities carried out during the entire 14-d study were recorded by each subject on a time sheet. Good subject compliance and the provision of careful instructions for their use also helped the investigators obtain more precise information for individuals.

Energy costs of each activity were then assigned from published values complied by the WHO. There is evidence to indicate that the activity-specific energy costs complied by the WHO reports[6] may not be applicable to human populations throughout the world. Therefore, we also measured the energy costs of some selected activities using the Cosmed $K4b^2$ portable metabolic system. The activities chosen for measurement of energy expenditures were those in which the subjects spent most of their time during the study, which included sitting in a chair, walking at the subject's own pace, watching TV, and reading and lying in bed. Comparison of our results with those of WHO suggests that the PAR values obtained from the WHO report for activities performed by the subjects are reasonable estimates of true energy costs[15].

Therefore, the reasons listed above may explain why the factorial method gives satisfactory estimates of EE for both groups and individuals in this study. Our results are in agreement with Warwick et al.[16] who compared factorial and chamber measures of 24-h EE in 13 subjects (seven males and six females) and found that agreement between measured and predicted 24-h EE was within ±2% for group results and ±10% for most individuals. Additionally, individual agreement was improved to within ±5% by using measured rather than predicted BMR. No difference was observed for each sex and age group. Morio et al.[4] validated the factorial method against the DLW technique for determining daily EE of elderly people in free-living conditions in 12 healthy subjects (six males and six females). It was concluded that the factorial method is a satisfactory alternative to the DLW method. In addition, when the reference value (i.e. sleeping metabolic rate) was accurately measured, individual agreement was improved. These findings indicate that direct measurements of BMR and EE of the various activities are required to improve the accuracy of the factorial method in individuals. However, different results were found by Acheson et al.[17-19] These authors demonstrated that assessment of factorial methods against other field methods showed reasonable or good agreement for groups but not for individuals. Although errors may also have occurred in the methods used for comparison and the use of predictive equations to estimate BMR, the primary variable is due to variation in physical activity. The energy expended for physical activity varies greatly among individuals as well as from day to day. Some degree of inaccuracy must be expected in the factorial method from potential errors in estimating energy costs of different activities, especially from using the same energy values for all individuals. In sedentary individuals, approximately two-thirds of total EE is used to sustain basal metabolism over 24 h, while one-third is used for physical activity. In very active individuals, 24-h total energy expenditure can rise to twice as much as basal energy expenditure, while even higher total expenditure occurs among heavy laborers and some athletes[6]. Activity-related EE individual differences in EE for the same activity can be large and the true energy cost for a person may or may not be close to the stated mean PAR value complied by the WHO. The potential for error increases in the free-living situation with an increasing level and variety of activity. In the current study, subjects were required to follow sedentary or light-activity lifestyles and the BMR was the major determinant of 24-h EE. Our good agreement between the two methods may have been due to exclusion of exercise (and consequent variability) during 24-h EE measurements.

In our study, only 16 females were selected as our subjects because of the high cost of isotopes and analyses for the DLW method (~$1 500 USD per person). Although we standardized the participants and their living conditions to ensure the accuracy and representativeness of the experimental results, the small size of the study population was still a limiting factor. Further studies are needed to determine whether the same method and energy cost factors are applicable to other groups.

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REFERENCES

1. FAO/WHO/UNU. Energy and protein requirements. Report of a joint FAO/WHO/UNU expert consultation. Technical Report Series. World Health Organization, 1985.
2. Chinese Nutrition Expert Panel. Chinese dietary reference intakes. Chinese Light Industry Publishing House, Beijing, 1st, 2000.
3. Leonard WR, Katzmarzyk PT, Stephen MA, et al. Comparison of the heart rate-monitoring and factorial methods: assessment of energy expenditure in highland and coastal Ecuadoreans. Am J Clin Nutr,1995; 61, 1146-52.
4. Morio B, Ritz P, Verdier E, et al. Critical evaluation of the factorial and heart-rate recording methods for the determination of energy expenditure of free-living elderly people. Br J Nutr, 1997; 78, 709-22.
5. Alfonzo GG, Doucet E, Almeras N, et al. Estimation of daily energy needs with the FAO/WHO/UNU 1985 procedures in adults: comparison to whole-body indirect calorimetry measurements. Eur J Clin Nutr, 2004; 58, 1125-31.
6. FAO/WHO/UNU. Human Energy Requirements. Report of a joint FAO/WHO/UNU expert consultation. FAO food and nutrition technical report series No1. Food and Agriculture Organization, 2001.
7. Lukaski HC, Bolonchuk WW, Hall CB, et al. Validation of tetrapolar bioelectrical impedance method to assess human body composition. J Appl Physio, 1986; 60, 1327-32.
8. Ge KY. An Overview of Nutrition Sciences. People's Medical Publishing House, Beijing, 1st, 2004; 740. (In Chinese)
9. Pinnington HC, Wong P, Tay J, et al. The level of accuracy and agreement in measures of F_EO_2, F_ECO_2 and V_E between the Cosmed K4b^2 portable, respiratory gas analysis system and a metabolic Cart. J Med Sci Sports, 2001; 4, 324-35.
10. Weir JB. New methods for calculating metabolic rate with special reference to protein metabolism. J Physio, 1949; 109, 1-9.
11. NAHRES-4 International Atomic Energy Agency. The doubly-labeled water method for measuring energy expenditure: technical recommendations for use in humans, International Dietary Energy Consulting Group. 1990.
12. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet, 1986; 1, 307-10.
13. Liu JM, Xu ZN, Li Y et al. Comparative study between the pulmonary function equipment and Douglas-bag in Chinese adults. Chin J Prev Med, 2010; 44, 795-9. (In Chinese)
14. McLaughlin JG, King GA, Howley ET, et al. Validation of the COSMED K4b^2 portable metabolic system. Int J Sports Med, 2001; 22, 280-4.
15. Liu JM, Li Y, Yang XG. The measurement of the energy expenditures in daily physical activities with K4b^2. Sci Tech

Engng, 2010; 10, 1215-8. (In Chinese)
16. Warwick PM, Edmundson HM, Thomson ES. Prediction of energy expenditure: simplified FAO/WHO/UNU factorial method vs continuous respirometry and habitual energy intake. Am J Clin Nutr, 1988; 48, 1188-96.
17. Butte NF, Treuth MS, Mehta NR, et al. Energy requirements of women of reproductive age. Am J Clin Nutr, 2003; 77, 630-8.
18. Matthews CE, Jurj AL, Shu XO, et al. Influence of exercise, walking, cycling, and overall nonexercise physical activity on mortality in Chinese Women. Am J Epidemio, 2007; 165, 1343-50.
19. Warwick PM , Baines J. Energy expenditure in free-living smokers and nonsmokers: comparison between factorial, intake-balance, and doubly labeled water measures. Am J Clin Nutr, 1996; 63, 15-21.