Original Article

Measurement of the Thermic Effect of Food in a Chinese Mixed Diet in Young People*

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Abstract

Objective To determine the thermic effect of food (TEF) in a Chinese mixed diet in young people.

Methods During the study, the participants were weighed and examined for body composition every morning. The total energy expenditure (TEE) of the participants was measured by the doubly labeled water method for 7 days, and during this period, basal energy expenditure was measured by indirect calorimetry and physical activity energy expenditure was measured by an accelerometer. The value obtained by subtracting basal energy expenditure and physical activity energy expenditure from TEE was used to calculate TEF.

Results Twenty healthy young students (18–30 years; 10 male) participated in the study. The energy intake of the participants was not significantly different from the Chinese Dietary Reference Intake of energy ($P > 0.05$). The percentage of energy from protein, fat and carbohydrate were all in the normal range. The intakes of fruits, milk and dietary fiber of the participants were significantly lower than those in the Chinese Dietary Guidelines ($P < 0.05$). There was no significant difference in the body weight of the participants during the experiment ($P > 0.05$). When adjusted for body weight, there was no significant difference in either TEE or basal energy expenditure between the male and female participants ($P > 0.05$). In addition, there was no significant difference in physical activity energy expenditure and TEF between the male and female participants ($P > 0.05$). The percentage of TEF in TEE was 8.73%.

Conclusion The percentage of TEF in TEE in a Chinese mixed diet in young people was significantly lower than 10% ($P < 0.001$). A value of 10% is usually considered to be the TEF in mixed diets as a percentage of TEE.

Key words: Thermic effect of food; Chinese mixed diet; Total energy expenditure; Basal energy expenditure; Physical activity energy expenditure; Doubly labeled water

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INTRODUCTION

The thermic effect of food (TEF), also called dietary induced thermogenesis or specific dynamic action, is the increase in metabolism after a meal and accounts for approximately 3%–10% of total energy expenditure (TEE)[1,2]. The TEF of a mixed diet is generally considered to be 10% of TEE[1]. A mixed diet consists of a variety of foods with complex combinations of

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components[3], but there is no exact definition of a mixed diet in the world. Different countries have different dietary patterns, so the food types and combinations of mixed meals are different. TEF is affected by some dietary factors. For example, it is affected by meal composition. Foods rich in dietary fiber, such as whole grains, beans, vegetables, and fruits, consume more energy during digestion and can therefore increase TEF[1,4,5]. In addition, high-protein meals as opposed to high-fat or high-carbohydrate meals tend to increase TEF[6,7].

Most of the TEF data are from European and American countries[1], and research on the TEF of a Chinese mixed diet is lacking. The dietary pattern of a Chinese mixed diet, which is mainly cereal based, is quite different from that of foreign countries; the dietary patterns of Western countries, for example, are characterized by increased intakes of saturated fats, red meat and sweets[8,9]. Even compared with the Mediterranean diet, the Chinese mixed diet has some differences; for example, the Chinese mixed diet contains more soy products and less dairy and wine than the Mediterranean diet[10]. Thus, it is unclear whether foreign data on TEF are applicable to a Chinese mixed diet.

TEF is indirectly calculated as the area between the energy expenditure (EE) and resting metabolic curves[2]. The most widely used method is to measure resting metabolic rate (RMR) directly preceding the given test meal, and TEF is calculated as the EE over and above the premeal-measured RMR[11]. The TEF response lasts 6 hours or more and up to 10 hours after large meals (up to 1,000 kcal); therefore, the only RMR measure unaffected by prior energy intake may be the initial fasted pre-breakfast measure because of the overnight fast during sleep[2,12]. Furthermore, the residual TEF from the prior meal will lead to an underestimation of the TEF for lunch and dinner.

In practice, TEF is usually used as a percentage of the TEE of a day (TEF%) to evaluate the energy consumption related to food ingestion, while TEF of a specific meal is rarely used. Because it is difficult to accurately measure the TEF of lunch and dinner, the method of calculating the TEF% by measuring the sum of TEF for breakfast, lunch and dinner will probably underestimate the true result. TEE includes basal energy expenditure (BEE), TEF, and physical activity energy expenditure (PAEE)[13], so TEF can be calculated indirectly by accurately measuring TEE, BEE and PAEE to avoid underestimating TEF.

In addition, TEF decreases with age[13], so it is necessary to determine TEF for different age groups. The dietary patterns of young people reflect, to some extent, the characteristics of a Chinese mixed diet under current socioeconomic conditions. Therefore, in the present study, we used young people as participants to calculate the TEF% of a Chinese mixed diet by measuring TEE through the doubly labeled water method, BEE by indirect calorimetry and PAEE by the accelerometer method.

METHODS

Participants

A priori power analysis was conducted using G*Power 3.1 (University Düsseldorf, Germany). According to the study of Yao et al.[14], the effect size of TEE between adult men and women in China was 10, and the total sample size calculated by G*Power was 4, which is a very small sample size. Considering our research funds, we expanded this sample size fivefold to include 20 participants. The inclusion criteria were healthy young people aged 18–30 years who were willing to participate in the study. All participants were screened by means of a daily activity questionnaire, physical examinations and blood tests (activity of liver enzymes, concentrations of thyroid hormones, blood glucose, insulin, albumin, hemoglobin, urea, creatinine and uric acid). Exclusion criteria were as follows: picky eaters (people who rarely eat certain food because they do not like it or are allergic to it), taking any nutritional supplements in the past 3 months, current smokers, habitual caffeine or alcohol intake (people who habitually consume caffeinated beverages or alcohol every day), a history of circadian or sleep disorders, body mass index < 18.5 kg/m^2 or ≥ 24.0 kg/m^2, chronic disease and endocrine disorders, and those who were expected to be menstruating during the experiment. Ten healthy young men and the same number of healthy young women from Yangzhou University were recruited. The purpose of the study and the potential risks involved were explained fully to each participant and written consent was obtained. Approval from the Ethical Review Committee of Yangzhou University was also obtained (NO. YZUHL2021031). All procedures were carried out in accordance with the standards stated in the 2013 version of the Helsinki Declaration.

Study Design

Before the experiment, the participants were given dietary guidance according to the Chinese Dietary Guidelines[15]. Throughout the 7-day experiment, participants were asked to choose the foods and drinks that they would like to consume according to the Dietary Guidelines[15]. The participants were encouraged to continue their normal occupations and leisure activities. The TEE of the participants was measured by the doubly labeled water method for 7 days, and during this period, BEE was measured by indirect calorimetry and PAEE was measured by the accelerometer every day. The participants were weighed and examined for body composition (EX/COM DF850 body composition analyzer, Japan) based on bioelectrical impedance analysis every morning. The participants were asked to have duplicate portions of meals, beverages and snacks every day during the experiment. One portion was consumed by the participants and the other was collected for laboratory analysis. All foods and drinks in each meal were weighed accurately and recorded both before and after consumption by each participant to determine the actual intake. Food samples were stored at −20 °C until analyses. Participants were asked to take photos of all the foods and drinks on their mobile phones before each meal and send them to the researchers. Furthermore, participants were required to give the dietary record form and exercise record form to the researchers every night. The researchers reviewed the logic and rationality of the contents of the record form and asked the participants to correct them in time if problems were found.

Measurement of TEE

The TEE of the participants was measured by the doubly labeled water method with reference to previous studies[14,16,17]. Briefly, on the morning of the labeling day after a 12-hour overnight fast, immediately after collecting a baseline urine sample (10 mL), doubly labeled water (Huayi Isotope, Changshu, China, with the enrichment of 10% ^{2}H and 10% ^{18}O) was given orally to each participant at a dose of 1 g/kg·bw and was followed with two 50 mL purified water rinses of the dose container. A breakfast consisting of two slices of white bread and 500 mL of pure milk was given an hour after dosing. The participants were then required to remain sedentary and not to consume any food or water while urine samples (10 mL) were collected at 3, 4, and 6 hours after the doubly labeled water administration (the first two samples were taken for equilibration purposes[14] and the third sample was used for testing). On the following 6 days, urine samples (10 mL) were collected at 07:00 every morning. The tap water used for cooking was also collected. All samples were aliquoted into airtight storage tubes immediately after collection and stored at −20 °C until analysis.

All samples were analyzed at the Createch Testing (Tianjin) Technology Co., Ltd with Nu perspective (Nu Instruments, Wrexham, UK) and MAT 253 plus (Thermo Fisher, San Jose, CA USA) stable isotope mass spectrometers for ^{2}H and ^{18}O, respectively. In the oxygen isotope test, the standards WICO-1, WICO-3, and WICO-5 were used. The recommended values of the standards were as follows: WICO-1, δ^{18}OV-SMOW‰ = −10.8; WICO-3, δ^{18}OV-SMOW‰ = −22.0; and WICO-5, δ^{18}OV-SMOW‰= −15.68. A correction curve was made with the test values and the recommended values of WICO-1, WICO-3, and WICO-5 were used as the quality control sample. In the hydrogen isotope test, the recommended values of the standards of WICO-1, WICO-3, and WICO-5 were δDV-SMOW‰ = −77.5 for WICO-1, δDV-SMOW‰ = −168.5 for WICO-3 and δDV-SMOW‰ = −114.5 for WICO-5. A correction curve was made with the test values and the recommended values of WICO-1, WICO-3, and WICO-5 were used as the quality control sample.

The TEE was calculated according to the method of Zhuo et al.[16]. Briefly, the carbon dioxide production rate (rCO_2) was calculated from the average total body water and the isotope elimination rate of ^{18}O and ^{2}H. The food quotient (FQ) was calculated using the total protein, lipids and carbohydrate intakes during the experiment. FQ = 0.8 × percentage of energy from protein + 0.71 × percentage of energy from lipids + 1 × percentage of energy from carbohydrate. The nitrogen content of food was determined by Kjeldahl analysis, lipid content was measured by Soxhlet extraction and acid solution, the contents of water and ash were detected by the weight method, and the total dietary fiber content was determined by the enzymatic-gravimetric method[18]. Carbohydrate content was determined by the subtraction method: carbohydrate content (g/100 g) = 100 − protein content (g/100 g) − lipid content (g/100 g) − water content (g/100 g) − ash content (g/100 g) − dietary fiber content (g/100 g). TEE was calculated using the modified Weir's equation: TEE (kcal/d) = rCO_2 (L/d) × (1.10 + 3.90/FQ).

Measurement of BEE

The BEE of participants was measured through indirect calorimetry with the CORTEX METAMAX 3B (Cortex Biophysik, Leipzig, Germany). After an overnight fast of 10–12 hours, measurement was taken when participants were fully awake, lying quietly and relaxed, and under thermoneutral conditions[19]. The temperature and humidity of the room were adjusted through air conditioning. Participants wore a ventilated mask through which air was drawn at a constant rate into an analyzer that measured the relative concentrations of oxygen and carbon dioxide in inspired and expired air. Rates of oxygen consumption (VO_2) and carbon dioxide production (VCO_2) were measured over 20 min. Data from the first 5 min were excluded, and the remaining data were averaged. Heart rate and respiratory rate were simultaneously monitored to track the participant's anxiety level. BEE was calculated from the VO_2 and VCO_2 measurements with Weir's equation[20]. Barometric calibration and capacity calibration were carried out before the start of each measurement, and gas calibration was performed once a week following the manufacturer's guidelines.

Calculation of the Physical Activity Level (PAL)

From TEE and BEE, PAL could be calculated according to the following formula: PAL = TEE ÷ BEE[21].

Measurement of PAEE

During the 7 days of the TEE experiment, the participants were instructed to wear a triaxial accelerometer (ActiGraph GT9X Link, Pensacola, FL USA) at the waist from waking up in the morning to going to bed at night. The accelerometer was charged and initialized before use and the start time was set according to the study plan. The triaxial accelerometer captured and recorded high resolution human activity information using a solid state 3-axis MEMS accelerometer. The accelerometer gave its outputs as counts per period of time and estimated EE by converting its counts/min into kcal. If participants were not wearing their accelerometer during swimming, bathing, or for other reasons, or were wearing the accelerometer while riding a bicycle, they were required to record the type of physical activity and the start and end times of the above activities. The energy consumption of these activities was calculated according to the formula: EE (kcal) = 0.9 × (metabolic equivalent − 1.0) (kcal $kg^{-1}\cdot h^{-1}$) × activity time (h) × body weight (kg), where 0.9 was to correct for TEF, which was assumed to be 10% of TEE, and 1.0 accounted for the resting energy expenditure [1 Metabolic equivalents (MET)][22]. Then PAEE was calculated according to the formula: PAEE = EE measured by accelerometer + EE when active but not wearing + EE while cycling.

Calculation of TEF

From the measured data of TEE, BEE, and PAEE, the average TEF per day of participants was calculated according to the following formula: TEF = TEE – BEE − PAEE, and TEF% = TEF ÷ TEE × 100%.

Statistical Analysis

The quantitative data are presented as mean ± standard deviation for variables with a normal distribution or as median (interquartile range) for variables with a skewed distribution. For variables with a normal distribution, differences between men and women were examined by independent sample *t*-tests, and differences between sample means and population means were examined by one-sample *t*-tests. If a test of normality failed, a non-parametric test (Mann-Whitney *U* test) was used. All statistical tests were two-sided hypothesis tests performed at the 5% level of significance. Data were analyzed using SPSS version 20 (IBM, Armonk, NY, USA).

RESULTS

Participant Characteristics

One female participant dropped out for health reasons; therefore, 10 male and nine female participants completed the experiment. The age, height, weight, body mass index and body composition of the participants are shown in Table 1. There was no significant difference in age between the male and female participants ($P > 0.05$). The height, weight, body mass index, and muscle percentage of the male participants were significantly higher than those of the female participants ($P < 0.05$), while the fat percentage was significantly lower than that of female participants ($P < 0.05$). There was no significant difference in the body weight and body composition of the participants every day ($P > 0.05$).

Intakes of Food, Energy and Macronutrients

Table 2 shows the food intake of the participants during the experiment. The intakes of cereals, tubers, fish, poultry, meat and eggs in male participants were significantly higher than those in female participants ($P < 0.05$). Accordingly, as shown in Table 3, the intakes of carbohydrate, protein and energy of male participants were significantly higher than those of female participants ($P < 0.05$). The

Table 1. Participant characteristics

Characteristics	Male (*n* = 10)	Female (*n* = 9)	*P*-value
Age (year)	21.90 ± 1.29	21.50 ± 1.90	0.559
Height (cm)	176.70 ± 6.34	162.30 ± 4.69	**< 0.001**
Body weight (kg)	68.71 ± 5.14	53.89 ± 4.25	**< 0.001**
Body mass index (kg/m^2)	22.00 ± 1.16	20.45 ± 1.19	**0.008**
Percent body muscle (%)	36.91 ± 3.22	28.34 ± 1.80	**< 0.001**
Percent body fat (%)	21.1 ± 4.66	31.64 ± 2.62	**< 0.001**

Note. Values are mean ± standard deviation. Bold numbers indicate a significant difference (*P* < 0.05) between male and female participants.

Table 2. Food intakes of the participants

Food intakes	Male (*n* = 10)	Female (*n* = 9)	Total[#] (*n* = 19)	Intake recommended in Chinese dietary guideline[*]	*P*-value
Cooked cereals and tubers (g/d)	737.8 (173.9)	558.7 (176.99)	717.34 (222.91)	250–400	**< 0.001**
Cooked vegetables (g/d)	213.16 (112.60)	142.37 (104.19)	208.56 (111.76)	300–500	0.086
Fruits (g/d)	12.44 (57.85)	18.51 (66.13)	12.75 (60.86)	200–350	0.842
Cooked soybean and nuts (g/d)	142.68 (196.06)	33.45 (74.52)	48.16 (186.98)	25–35	0.079
Cooked fish, poultry, meat and eggs (g/d)	375.17 (150.51)	252.40 (111.13)	334.87 (122.44)	120–200	**0.006**
Milk (g/d)	110.37 (44.58)	161.31 (296.21)	150.06 (121.32)	300–500	0.113

Note. Results are presented as median (interquartile range). [#]Results are presented as the intake of a standard person. A standard person is an 18-year-old man engaged in light physical activity, with an estimated energy requirement of 2,250 kcal. Food intake of a standard person = food intake of a participant ÷ (estimated energy requirement of the participant ÷ 2,250). [*]Intake is the raw weight of the edible part of the food. Bold numbers indicate a significant difference (*P* < 0.05) between male and female participants.

Table 3. Intakes of energy and macronutrients of the participants

Variables	Male (*n* = 10)	Female (*n* = 9)	Total[#] (*n* = 19)	Chinese dietary reference intakes[*]	*P*-value
Energy (kcal/d)	2355.06 ± 326.20	1891.23 ± 261.80	2359.31 ± 317.52	2,250	**0.003**
Protein (g/d)	83.92 ± 16.61	68.35 ± 11.65	84.64 ± 15.26	65	**0.032**
Percentage of energy from protein (%)	14.23 ± 1.65	14.55 ± 1.84	14.38 ± 1.70	10–20	0.691
Percentage of high-quality protein (%)	36.80 ± 4.06	37.98 ± 4.30	37.36 ± 4.10	30–50	0.548
Fat (g/d)	77.51 ± 17.00	64.99 ± 16.69	79.28 ± 18.48	50–75	0.124
Percentage of energy from fat (%)	29.62 ± 4.61	30.80 ± 4.94	30.18 ± 4.68	20–30	0.597
Carbohydrate (g/d)	341.29 ± 47.87	262.33 ± 40.53	334.29 ± 48.31	120	**0.001**
Percentage of energy from carbohydrate (%)	58.42 ± 6.62	55.94 ± 5.05	57.24 ± 5.90	50–65	0.376
Dietary fiber (g/d)	6.84 ± 1.18	6.33 ± 2.10	7.35 ± 2.02	25	0.530

Note. Values are mean ± standard deviation. [#]Results are presented as the intake of a standard person. A standard person is an 18-year-old man engaged in light physical activity, with an estimated energy requirement of 2,250 kcal. Energy intake or macronutrient intake of a standard person = energy intake or macronutrient intake of a participant ÷ (estimated energy requirement of the participant ÷ 2,250). [*]For men aged 18–50 years, data for energy and carbohydrate are Estimated Average Requirement (EAR), data for protein are Recommended Nutrient Intake (RNI) and data for dietary fiber are Adequate Intake (AI). Bold numbers indicate a significant difference (*P* < 0.05) between male and female participants.

intakes of fruits, milk and dietary fiber of the participants were significantly lower than those in the Chinese Dietary Guidelines (P < 0.05). Moreover, the energy proportions from protein, fat and carbohydrate of the participants were all reasonable according to the Chinese Dietary Guidelines, and there was no significant difference between the total energy intake of the participants and the Chinese Dietary Reference Intake of energy[23] (P = 0.15).

TEE of the Participants

The TEE was significantly higher in men than in women (P < 0.05), but there was no significant difference in the TEE adjusted for body weight between male and female participants (P > 0.05) (Table 4). There was no significant difference between TEE and the estimated energy requirement proposed by the Chinese Nutrition Society in 2013[23] (P_{male} = 0.34, P_{female} = 0.33). In addition, there was no significant difference between TEE and the energy intake of the participants (P_{male} = 0.17, P_{female} = 0.29).

BEE of the Participants

As shown in Table 5, there was no significant difference in the measurement conditions of BEE between the male and female participants (P > 0.05). The BEE of the male participants was significantly higher than that of the female participants (P < 0.05), but there was no significant difference in BEE after adjustment for body weight (P > 0.05).

PAEE of the Participants

Table 6 shows the physical activity of the participants. Although there were significant differences in sedentary time and light physical activity time between the male and female participants (P < 0.05), there was no significant difference in the total PAEE between the men and women (P > 0.05).

PAL of the Participants

The PAL of the male and female participants were 1.37 ± 0.08 and 1.49 ± 0.07, respectively, and there was a significant difference in PAL between the men and women (P < 0.05).

TEF of the Participants

As shown in Table 7, there was no significant difference in TEF between the male and female

Table 4. The total energy expenditure of the participants

Variables	Male (*n* = 10)	Female (*n* = 9)	Total (*n* = 19)	*P*-value
rCO_2 (L/d)	417.73 ± 39.34	325.53 ± 26.19	368.07 ± 51.81	**< 0.001**
TEE (kcal/d)	2182.54 ± 191.44	1785.74 ± 116.70	1994.58 ± 256.53	**< 0.001**
Body weight corrected TEE [kcal/(kg·d)]	31.76 ± 1.24	33.12 ± 2.45	32.40 ± 1.98	0.160

Note. Values are mean ± standard deviation. Bold numbers indicate a significant difference (P < 0.05) between male and female participants.

Table 5. Measurement conditions and results of basal energy expenditure

Variables	Male (*n* = 10)	Female (*n* = 9)	Total (*n* = 19)	*P*-value
Room temperature (°C)	23.77 ± 0.94	23.17 ± 1.37	23.49 ± 1.14	0.273
Room humidity (%)	51.30 ± 9.45	54.78 ± 7.58	52.95 ± 8.56	0.392
Body temperature (°C)	35.78 ± 0.43	35.88 ± 0.53	35.83 ± 0.47	0.664
Heart rate (bpm)	66.31 ± 10.16	61.35 ± 4.75	63.96 ± 8.25	0.189
Breathing rate (n/min)	14.79 ± 2.51	15.62 ± 2.81	15.18 ± 2.61	0.506
Respiratory exchange rate (%)	0.84 ± 0.04	0.86 ± 0.08	0.85 ± 0.05	0.322
VO_2 (L/min)	0.23 ± 0.01	0.17 ± 0.01	0.20 ± 0.01	**< 0.001**
VCO_2 (L/min)	0.18 ± 0.03	0.14 ± 0.01	0.16 ± 0.02	**< 0.001**
BEE (kcal/d)	1574.61 ± 100.26	1191.18 ± 53.31	1392.99 ± 212.08	**< 0.001**
Body weight corrected BEE [kcal/(kg·d)]	22.95 ± 0.97	22.09 ± 1.22	22.55 ± 1.15	0.101

Note. Values are mean ± standard deviation. Bold numbers indicate a significant difference (P < 0.05) between male and female participants.

participants ($P > 0.05$). The TEF% (8.73%) of all the participants was significantly lower than 10% (examined by a one-sample *t*-test; $P < 0.001$). A value of 10% is usually considered to be the TEF% of a mixed diet[1].

DISCUSSION

TEE of healthy adults consists of three components: BEE (60%–75% of TEE), PAEE (15%–30% of TEE) and TEF (10% of TEE)[24]. The doubly labeled water method is usually considered the gold standard for assessing TEE under daily living conditions[25,26]. Indirect calorimetry, which is based on the measurement of oxygen consumption and carbon dioxide production, is the preferred method to accurately assess BEE[27]. In addition, accelerometers are typically viewed as the gold standard in PAEE assessment for healthy adults[22,28]. In the present study, the above standard or typical methods were used to measure TEE, BEE, and PAEE, and then TEF was calculated by subtracting BEE and PAEE from TEE. The methods used avoided the underestimation of TEF for lunch and dinner that can result from the early termination of measurements before postprandial metabolic rates have fully returned to baseline levels[2,29].

Throughout the experiment, the body weight of the participants remained stable, which was consistent with the result that there was no significant difference between energy intake and TEE. Furthermore, the stability of body weight ensured the reliability of the result of the doubly labeled water experiment. As can be seen from the results, there was no significant difference in TEF% between the male and female participants. There is a lack of consensus in the literature regarding sex differences in TEF. Some studies have shown significantly lower TEF in women as a percent of energy content of a test meal and as absolute values[30,31]. By contrast, Martinez-Tellez et al.[32] found that a standardized and individualized liquid meal test increased the skin temperature more in young female than male adults, indicating that the thermic effect was higher in women than in men. The main reason for the inconsistent results may be that the age and body composition of the participants in the above studies varied greatly, and TEF decreases with age and with body fat[13,33,34]. Insulin sensitivity plays a role in metabolism, and particularly affects TEF[1]. Obese people have a higher risk of insulin resistance, which will lead to a

Table 6. Physical activity of the participants

Variables	Male (*n* = 10)	Female (*n* = 9)	Total (*n* = 19)	*P*-value
Length of time in Sedentary physical activity (min/d)	1227.28 ± 56.42	1153.32 ± 71.62	1188.79 ± 75.02	**0.014**
Sedentary/total (%)	85.23	80.09	82.56	**0.014**
Length of time in Light physical activity (min/d)	160.58 ± 53.38	224.19 ± 66.88	192.81 ± 69.15	**0.027**
Light/Total (%)	11.15	15.57	13.39	**0.027**
Length of time in moderate to vigorous physical activity (MVPA) (min/d)	52.15 ± 15.47	62.49 ± 31.69	58.40 ± 25.04	0.263
MVPA/total (%)	3.62	4.40	4.06	0.263
METs [kcal/(kg·h)]	1.13 ± 0.06	1.13 ± 0.06	1.13 ± 0.06	0.830
PAEE (kcal/d)	419.29 ± 109.84	436.03 ± 84.99	427.22 ± 96.52	0.717

Note. Values are mean ± standard deviation. Bold numbers indicate a significant difference ($P < 0.05$) between male and female participants. PAEE, Physical activity energy expenditure; METs, Metabolic equivalents; MVPA, Moderate to vigorous physical activity.

Table 7. The thermic effect of food of the participants

Variables	Male (*n* = 10)	Female (*n* = 9)	Total (*n* = 19)	*P*-value
TEF (kcal/d)	188.64 ± 40.71	158.53 ± 20.43	174.38 ± 35.39	0.062
TEF%	8.60 ± 1.57	8.87 ± 0.92	8.73 ± 1.28	0.651

Note. Values are mean ± standard deviation. The level of statistical significance was set at $P < 0.05$. TEF, thermic effect of food.

higher risk of TEF decline. In the present study, there was no significant difference in the ages of the male and female participants. Although the percentage of body fat in the men was lower than that of the women, there was no significant difference in the levels of blood sugar and insulin between the men and women, indicating that there was no difference in insulin sensitivity between the participants of different sexes in the present study.

In previous studies, physical activity has increased TEF, regardless of age or body composition[35]. The PAL of the participants in the present study was sedentary or extremely inactive, which was similar to the PAL of the participants during the detection of TEF by the measurement of RMR through indirect calorimetry. Although the light physical activity time of the female participants was significantly longer than that of the male participants, there was no significant difference in METs between the sexes. Although we did not find the calculation formula of PAEE in the ActiGraph GT9X Link user manual, we speculate that PAEE is probably calculated based on the following formula: PAEE (kcal/d) = 0.9 × MET [kcal/(kg·h)] × exercise time (h) × body weight (kg) − 0.9 × 1.0 [kcal/(kg·h)] × exercise time (h) × body weight (kg), where 0.9 is to correct for TEF (which is assumed to be 10% of TEE) and 1.0 accounts for the resting energy expenditure (1 MET)[22]. Because the body weight of the men was significantly higher than that of the women, whereas the exercise time of the men was significantly shorter than that of the women, multiplying exercise time by body weight was likely to produce no difference between the male and female participants. We speculate that this was the main reason why no significant difference was found between the PAEE of the male and female participants.

In addition, dietary factors, such as the energy content of meals, meal composition and macronutrient intake, especially protein intake, can affect TEF[1]. A higher energy intake, regardless of meal composition, results in increased TEF[1,36]. Thearle et al.[37] measured TEF% in a Western diet with 20 participants (15 men and five women). The participants had varied ethnicities, including three African Americans, seven Caucasians, two Hispanic and eight Native American individuals. The average age was 36.7 years and 12 participants were obese. In this study, the TEF% was 9.7%, which is higher than that in the present study (8.7%). The energy intake in the study by Thearle et al. was 2,273 kcal/d, which is not significantly different from that in the present study (2,359 kcal/d). Moreover, the total energy intake of the participants in the present study was not significantly different from the Chinese Dietary Reference Intake of energy. This finding indicates that the daily energy intake of the participants in the present study was appropriate and would not have had an atypical effect on TEF. Although the percentages of energy from protein, fat and carbohydrate were all in the normal ranges in the present study[23], the percentage of energy from protein (14%) was significantly lower than that in the study of Thearle and coworkers (20%). The percentage of energy from carbohydrates in the present study (57%) was significantly higher than that in Thearle's study (50%); there was no significant difference in the percentage of energy from fat (30%) between the two studies. Because TEF values are approximately 20%–30% for protein, 5%–10% for carbohydrate and 0%–3% for fat, the lower energy supply ratio of protein in the present study was probably the main reason for TEF% being lower than that in Thearle's study.

The intake of dietary fiber of the current participants was significantly lower than that in the Chinese Dietary Reference Intake (P < 0.05). The higher the dietary fiber in foods, the higher the energy needed to digest them, and so the higher the TEF[1,4,5]. Therefore, the insufficient intake of dietary fiber of the participants would reduce TEF. Compared with the dietary pattern recommended in the Chinese Dietary Guidelines[15], the dietary pattern in the present study was unhealthy. For example, the intakes of fruit and milk were insufficient, which is similar to the average dietary intakes of fruit and milk in Chinese residents. In China from 2015 to 2017, the average consumption of fruit and milk among people aged 18–59 years was 35 g and 17 g, respectively[38]. The lower intakes of fruit and milk may have contributed to the lower intakes of dietary fiber and protein, respectively.

Therefore, the results suggest that the TEF% of 10% may overestimate the thermic effect of food in the Chinese mixed diet for young people. If BEE and PAEE are known, TEE can be calculated according to the formula TEE = (BEE + PAEE)/(1 − TEF%). Thus, if TEE is calculated with TEF% = 10%, it may lead to an overestimation of TEE. There were several limitations of the study. First, the sample size was small. Second, the participants were all young university students. Because TEF decreases with age, the results of this study cannot be extrapolated to children and the elderly.

CONCLUSION

The TEF% in a Chinese mixed diet for young people in the present study was 8.7%, which is significantly lower than 10%, which is usually considered to be the TEF% of a mixed diet. A low percentage of energy from protein and low dietary fiber intake were the main reasons.

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AUTHORS' CONTRIBUTIONS

TIAN Ying designed the study and wrote the whole manuscript. CAO Hong Peng, HUAN Yu Ping, GONG Jia Wei, YUAN Kai Hua, CHEN Wen Zhuo, HU Jing and SHI Yu Fei performed experiments and examined the food samples. CAO Hong Peng and HUAN Yu Ping analyzed the data. All authors read and approved the final manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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