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Brief communication

# Does basal metabolic rate drive eating rate?

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ABSTRACT

There have been recent advances in our understanding of the drivers of energy intake (EI). However, the biological drivers of differences in eating rate (ER) remain less clear. Studies have reported that the fat-free mass (FFM) and basal metabolic rate (BMR) are both major components that contribute to daily energy expenditure (EE) and drive EI. More recently, a number of observations report that higher ER can lead to greater EI. The current study proposed that adults with a higher BMR and higher energy requirements would also exhibit higher ERs. Data on BMR, FFM, and ER were collected from 272 Chinese adults (91 males and 181 females) in a cross-sectional study. Analysis showed significant positive associations between BMR and ER ($r_s = 0.405$, $p < 0.001$), and between FFM and ER ($r_s = 0.459$, $p < 0.001$). BMR explained about 15% of the variation in ER which was taken to be metabolically significant. This association provides metabolic explanation that the differences in an individual's BMR (hence energy requirements) may be correlated with ERs. This merits further research.

## 1. Introduction

Energy balance (EB) is made up of two components namely, energy intake (EI) and energy expenditure (EE), *i.e.* EB = EI − EE. A considerable amount of research has centered on understanding the mechanisms that regulate both EI and EE and the potential underlying physiological differences that drive differences at an individual level [1]. Previously, glucose, fat and temperature were proposed to be involved in the regulation of food intake and were classified as the glucostatic, lipostatic and thermostatic theories regulating food intake [2–4]. However, studies over the years have shown that EI is not exclusively regulated by these signals [5,6]. In 1955, Edholm et al. [7,8] reported that EI was driven by daily EE, and proposed that EB was regulated through this mechanism. The largest component of EE (representing up to 70% of total EE) is the basal metabolic rate (BMR), which is the amount of energy per unit time that a person needs to keep the body functioning at rest. The total EE in adults can be compartmentalized into four components namely BMR, physical activity (22–30% of total EE), diet induced thermogenesis (10–15% of total EE) and growth component (< 2% of total EE) [9,10]. Indeed even in children, apart from the first year of life and during puberty where growth is a contributor, BMR still remains by far the largest component.

Interest in the role of BMR in determining EI emerged with the publication of the document *Energy and Protein Requirements* in 1985 [11] that proposed the use of EE (*i.e.* BMR) rather than food intake to calculate the energy requirements [12]. This unique approach focused considerable attention on BMR and its metabolic consequences. Previous research by Lissner et al. in 1989 [13] reported that EI was correlated with fat-free mass (FFM) and not fat mass (FM). This was a major observation as it denoted for the first time that a possible driver of EI may be an individual's energy requirement, contributed mainly by BMR. More recently Blundell and colleagues [14] have reported similar observations about the predictive power of the FFM on EI. Moreover, FFM was implicated as being an orexigenic (increase appetite) or ergostatic driver of meal size and EI [14].

A number of recent acute feeding studies, epidemiological reports and meta-analyses have demonstrated that eating rate (ER) can influence acute EI such that faster eaters tend to consume more energy than slower eaters within a meal. It is also correlated with greater BMI and adiposity among children and adults [15–20]. In addition, it has also been observed that there were large differences in ER between individuals consuming the same foods (with the same food textures) [18,20,21]. However, the association between ER and underlying differences in BMR and EI requirements has yet to be established. In a similar way to BMR [22], a recent study had also demonstrated that an individual's ER is consistent over time across multiple consumptions of the same meal, and predictive of EI [23]. This raises the possibility that there may be an underlying association between the metabolic requirement for energy to support a higher BMR, and the associated behavioural response to have a higher ER that supports increased EI.

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The current study seeks to explore whether there is a relationship between energy requirement, using BMR as a proxy estimate, and ER as a measure of an adaptive behaviour to support increased requirements for energy. Since ER has been shown to affect EI within and across meals, the question arises as to whether ER varies across individuals in a similar way to BMR. The goal of our study was to examine whether there is an association between ER and an individual's energy requirement, as explained by differences in their underlying BMR. We set out to (i) confirm the relationship between FFM and BMR in a large cross-sectional Asian cohort, (ii) test whether there is an association between BMR and ER, and (iii) test whether there is a relationship between FFM and ER (as this relationship is yet to be tested).

## 2. Methods and subjects

The data for this paper was obtained from a cross-sectional study conducted at Clinical Nutrition Research Centre (CNRC), Singapore between June 2015 and December 2016. The participants included 272 healthy adults aged 21 to 69 years old: 91 males (33.5%) and 181 females (66.5%). They were recruited through advertisement on newspaper and posters that were placed around the National University of Singapore campus, public area, and on the CNRC website. Eligibility included healthy males and females who were Singaporean or permanent resident, who had resided in Singapore for at least five years and were not diagnosed with any major diseases, taking any regular medication, or pregnant. All procedures involving human subjects were approved by the National Healthcare Group Domain Specific Review Board (Reference number: 2013/00783), Singapore. All participants gave written informed consent before starting.

### 2.1. Body composition and BMR

Weight (kg) was measured to the nearest 0.1 kg in light clothing without footwear by using an electrical weighing scale (Seca Limited, Birmingham, UK) and height (cm) was measured using a stadiometer (Seca Limited, Birmingham, UK) to the nearest 0.1 cm. BMR was measured using an indirect calorimeter (COSMED, Rome, Italy) in the fasted state (at least 12 h from 10 pm the night before the test day). Compliance to this protocol was checked using their completed diet record and a physical activity questionnaire for the day before the test session and on the day of the test session. The participants were instructed to lie in a supine position for 30 min, in a room maintained at thermo-neutral temperature (22–26 °C), without moving while a plastic canopy with veil was placed over the upper part of their body to prevent external air from entering the hood [24]. During the period of measurement, the participants were instructed to not sleep and to limit their movement. BMR was measured using the last 10 min of the measurement period to ensure stable and interpretable measurements are obtained [25]. The amount of $FeO_2$ was verified to be within 0.7%–1.3% throughout the test duration and was adjusted if necessary. Ergo (reference value for $O_2$: 1598, $CO_2$: 503) and air (reference value for $O_2$: 2093, $CO_2$: 4) calibration were done prior to measurements.

FFM was evaluated from body composition measures assessed using dual-energy X-ray absorptiometry (DXA, QDR 4500A, fan-beam densitometer, Hologic, Waltham, USA). It was calculated by using the manufacturer's software (software version 8.21). All anthropometric measurements were taken from the participants on the day they reported for the study.

### 2.2. Energy intake

On the morning of the test session, participants were requested to consume a standardised breakfast comprising a small packet of orange juice (Marigold: 250 mL; 46 kcal/100 mL) and two slices of white bread (Gardenia: 57 g × 2; 263 kcal/100 g) with kaya spread (NTUC FairPrice: 16 g; 300 kcal/100 g). This was consumed to standardize appetite need state 2 h before an *ad libitum* buffet lunch was served. The 2-h gap between breakfast and lunch was deemed appropriate to normalize appetite sensations following the standardised test breakfast, and was chosen to ensure all participants were in a similar need state at the beginning of the test meal, in line with previous studies in a similar test population [26]. The *ad libitum* buffet lunch consisted of 1000 g (189 kcal/100 g) of olive vegetable fried rice (JR Foods, Singapore; main ingredients: rice, egg, olive, garlic, and vegetable oil) and a glass of plain water (250 mL). The olive vegetable fried rice was reheated from frozen according to the manufactures instructions.

Olive vegetable fried rice was chosen as it was a familiar, contextually appropriate lunchtime test meal that was acceptable. This test lunch was chosen based on experience in previous studies [27] as it was not highly hedonically appealing, had a medium energy density (189 kcal/100 g), so as not to exaggerate differences in EI and was homogenous with limited variety to minimize the impact of variety on sensory specific satiety. Our previous studies have shown that minor changes in food liking had negligible effect on ER [23]. These factors in combination imply that the ER was measured objectively without being influenced by plausible confounding variables.

Participants were given 15 min to consume their lunch and were instructed to eat as little or as much as they wish until they feel comfortably full. The task was recorded on a webcam (Logitech HD c310) mounted on a computer and all participants were told that the session would be recorded, but they were unable to see themselves on the video display. Leftover rice and water were weighed using a Sartorius balance (Goettingen, Germany) and weight was recorded, to two-decimal places, to derive the amount consumed.

### 2.3. Behavioural coding of eating rate

The video recordings of the *ad libitum* lunch were coded by a trained assessor using a coding scheme to capture the total number of bites, chews and swallows and time in mouth. This coding scheme is described in detail elsewhere [28,29]. Using these measures, it was possible to derive a series of eating behaviours including average bite size, chews per bite, oral-processing time and eating rate (g/min or kcal/min). Videos were coded using behavioural annotation software ELAN (ELAN 4.9.2, Max Planck Institute for Psycholinguistics). Behavioural video coding was completed by a single trained video-coder and 10% of all coded videos were later blind-validated by the second trained video-coder, and only accepted as data when they surpass an agreement level of 80%. This is in line with the previously published recommendations [30]. Inter-rater reliability was further assessed using two-way mixed, consistency, single-measures to assess the consistency between coders based on 10% of the subjects. This resulted in high levels of agreement between the coders, ICC = 0.98 (95% CI, 0.96–0.99). Hence, duration of food in mouth as measured by the coder was deemed suitable for the current study. Average ER was calculated by dividing the grams consumed by the total oral exposure time (g/min) [28].

All statistical analysis in this study was done using Statistical Package for the Social Sciences (IBM SPSS version 24, IBM Corp, Armnok, NY, USA) and two-tailed statistical significance test was set at $\alpha = 0.05$. Following measures of association in this study were evaluated using Spearman's correlation as it is robust to deviations from the center. A minimum sample of 84 was necessary to achieve a medium sized correlation of 0.3 at 0.05 significance level with 80% power. The sample size of 272 used in this study was seen to be more than necessary.

## 3. Results and discussion

Table 1 shows characteristic data for the 272 Chinese participants recruited in the study. The average age of the participants was 39 years with BMI ranging from 16.3 kg/m$^2$ to 37.8 kg/m$^2$. The participant's ER varied widely from 8.6 g/min to 68.2 g/min. Table 1 shows that males