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Differences in correlates of energy balance in normal weight, overweight and obese adults

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Summary
Purpose: The purpose of this study was to examine differences in total daily energy expenditure (TDEE), energy expenditure in various intensities, as well as total daily energy intake (TDEI) and diet quality in normal weight, overweight and obese men and women. Further, the association of energy expenditure and energy intake with body fatness was examined.
Methods: The cross-sectional analysis included 430 adults (27.7 ± 3.8 years; 49.3% male). Body weight and height were measured according to standard procedures and percent body fat (BF) was assessed via dual X-ray absorptiometry. Energy expenditure was determined via the SenseWear Armband. Energy intake and the Healthy Eating Index (HEI) were calculated based on multiple 24-h recalls.
Results: Weight adjusted TDEI and TDEE were significantly lower in overweight and obese adults compared to their normal weight peers ($p < 0.001$) and obese women had a lower HEI ($p = 0.006$). Overweight and obese adults further displayed a higher proportion of energy expenditure spent in sedentary and in light activities ($p < 0.001$), while the proportion of energy expenditure in moderate-to-vigorous physical activity (MVPA) was lower compared to their normal weight peers

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($p < 0.001$). The inverse relationship between BMI or BF and MVPA was stronger than the positive association between BMI or BF and the proportion of energy expended in sedentary or light pursuits ($r_{MPA} = -0.45$ to -0.67/$r_{MVPA} = -0.51$ to -0.66 vs. $r_{Sedentary} = 0.33$ to 0.52/$r_{light} = 0.36$ to 0.47; $p < 0.001$).
Conclusions: These findings emphasise the importance of MPA and bouts of MVPA regarding the maintenance of a normal body weight.

Introduction

Sixty-nine percent of adults in the U.S. are considered to be overweight, including 36% who are obese [1]. These prevalence rates reflect a progressive upward shift in the distribution of BMI across all populations. Excess body weight has been associated with an increased risk for chronic diseases including cardiovascular disease, diabetes, many forms of cancer, and numerous musculoskeletal problems [2,3]. Further, it puts a significant economic burden on the society by contributing to significant medical costs [4,5].

An imbalance between energy intake and energy expenditure is the primary etiologic factor for the development of overweight and obesity. The regulation of energy balance, however, does not occur on a daily basis and relatively small discrepancies between energy intake and energy expenditure can have profound long-term effects on body weight and body composition [6]. While there is a genetic component to the accumulation of excess weight, environmental and behavioural changes have been suggested as the predominant contributor to the obesity epidemic [7].

Throughout the last decades there has been a decline in energy expenditure in various aspects of daily living [8,9] along with a change in dietary intake [10]. Despite a considerable amount of research on the regulation of energy balance there remains little information on differences in patterns of energy expenditure and dietary intake in normal weight, overweight and obese adults and on potential differences in the regulation of energy balance in different weight categories. A better understanding of how energy balance is achieved at different body weights could help in the development, implementation and evaluation of intervention programmes focusing on weight loss and weight maintenance, and more importantly on prevention of weight gain in the first place.

Several studies have examined the association between time spent at different intensities of physical activity (PA) and BMI [11—16]. These studies showed an inverse association between time spent in moderate-to-vigorous physical activity (MVPA) while the association between time spent sedentary or in light activity and BMI was less consistent and differed for men and women [12,14,16]. It has also been suggested that 45—60 min of MVPA per day are necessary to prevent a normal weight person from becoming overweight or obese [17]. Body weight and body composition, however, are determined by the balance of energy expenditure and energy intake rather than time spent in different intensities of PA. The present study, therefore, investigates potential differences in energy expenditure and energy intake among adults in different weight categories. Specifically, the purpose of this study was to examine differences in total daily energy expenditure (TDEE) and the proportion of energy expenditure in sedentary, light and MVPA as well as total daily energy intake (TDEI) and diet quality in normal weight, overweight and obese men and women. Further, the association between body fat percentage and these correlates of energy balance was examined.

Methods

Study design

The present analyses were performed using baseline data from a large observational study of primary and secondary determinants of weight change. The energy balance study's extensive methodology and demographics have been published previously [18]. Briefly, 430 (49.3% male) healthy adults aged 21—35 years with a BMI of 20—35 kg/m^2 provided baseline data. The age distribution of the participants included an evenly distributed range of young adults to early middle age.

Exclusion criteria were designed to select a broad group of healthy individuals with no major acute or chronic conditions who had not made any large changes in health behaviours in the previous months. Exclusion criteria also included pregnancy in the previous 12 months and planned births. In addition, due to concern over potential changes in body water and appetite, women who planned on changing their use of contraceptive medications during the study were excluded. The study protocol was approved by the University of South Carolina Institutional Review Board and is in accordance with the declaration of Helsinki.

All measurements were obtained by trained and certified research staff. Three baseline sessions were attended with measurements distributed over the sessions. Further, participants completed an extensive medical history and demographic information form, as well as activity recall questionnaires.

Anthropometrics and body composition

Height (cm) and weight (kg) were measured using standard laboratory procedures with participants in surgical scrubs after an overnight fast. Height was measured to the nearest 0.1 cm using a wall-mounted stadiometer (Model S100, Ayrton Corp., Prior Lake, MN, USA) and weight was measured to the nearest 0.1 kg using an electronic scale (Healthometer® model 500KL, McCook, IL, USA). The average of 3 measurements was used to calculate BMI (kg/m^2), which was subsequently used to differentiate between normal weight (BMI < 25), overweight ($25 \geq$ BMI < 30) and obese (BMI ≥ 30) participants.

Body composition was determined via dual X-ray absorptiometry (DXA; GE Healthcare Lunar model 8743, Waukesha, WI). Total fat and lean tissue mass, as well as torso, arm and leg tissue composition were recorded. Percent body fat was calculated as the DXA-reported fat mass divided by total body weight.

Energy intake and diet quality

Dietary intake was assessed via multiple 24-h diet recalls (24HR), which has been recommended as a viable assessment tool for dietary intake in a free living population [19]. Up to three 24HR, including weekdays and weekend days, were administered over the phone by a team of experienced registered dieticians over a period of 14 days. Participants were given a validated 2-dimensional food portion visual [20] and received 10—15 min of training on how to use it to estimate portion sizes of commonly eaten foods prior to the 24HR. Dietary data were analysed using the Nutrient Data System for Research software (NDSR Version2012; Nutrition Coordinating Center, University of Minnesota, Minneapolis, MN, USA). In order to be included in the analysis at least two 24HR needed be completed. Average values were used to calculate total daily energy intake (TDEI) and the Healthy Eating Index 2010 (HEI-2010), which assesses conformance of reported dietary intake with current recommendations [21]. The HEI-2010 provides a single score between 0 and 100, with higher scores indicating better diet quality.

Energy expenditure

Total daily energy expenditure (TDEE) and energy expenditure at different intensities of PA was assessed with the SenseWear Mini Armband (BodyMedia Inc., Pittsburgh, PA). The armband uses minute-by-minute measurements of tri-axial accelerometry, galvanic skin response, skin temperature, heat flux, and near body temperature to estimate energy expenditure using proprietary regression models (Version 7.0 professional). The armband has been shown to provide accurate estimates of total daily energy expenditure and energy expenditure at various intensities in free-living adults [22—24]. Participants were asked to wear the armbands continuously over a period of 10 days, except when armbands would be getting wet such as when participants were bathing/showering/swimming. Compliance was defined as seven days of wear (including two weekend days) during the 10-day measurement period with at least 21 h of verifiable time on each of the days. When the armband was not on-body participants recorded their activities in a log that was provided to the investigators. The investigators then matched these periods of non-wear time to metabolic equivalents (METs) of these activities based on the 2011 Compendium of Physical Activities [25]. These METs were then multiplied by the participant's resting metabolic rate (RMR) to compute energy expenditure for the time when the armband was not worn. The measurement of RMR was conducted using indirect calorimetry (True One 2400, Parvo Medics, Sandy, UT) with participants reporting to the laboratory in the morning after a 12-h fast and 24 h abstention from exercise.

Minute-by-minute data were subsequently classified into categories of non-sleeping sedentary behaviour (sedentary < 1.5 METs), light PA (1.5—2.9 METs), moderate PA (MPA, 3.0—5.9 METs), vigorous PA (VPA, $\geq$6.0 METs) and bouts of at least 10 min of uninterrupted MVPA ($\geq$3.0 METs). In addition to absolute energy expenditure in the respective intensities, the proportion of energy expenditure in these PA intensities was calculated by dividing the energy expenditure in these categories by TDEE excluding sleep to account for differences in energy expenditure due to differences in body weight and body composition.

Statistical analyses

Mean differences among weight categories were examined via 2-way (sex by weight category) ANOVA. As there were no significant interaction effects between sex and weight category subsequent analyses were carried out separately for men and women using Bonferroni adjustment for post hoc tests. Pearson's correlations were used to determine the relationships between BMI or body fatness of women and men and potential determinants of energy balance including TDEI/kg, TDEE/kg and the proportion of energy expenditure at different intensities. The strength of the relationship was defined, for positive and negative trends, as strong ($r > 0.5$), moderate ($0.5 \leq r \leq 0.3$), or weak ($0.3 < r < 0.1$) [26]. As not all participants provided complete or valid data for energy intake and energy expenditure, sample size varies for different analyses. All analyses were carried out with SPSS® 21.0 (SPSS Inc., Chicago, IL, USA) with a significance level of $\alpha = 0.05$ using Bonferroni adjustment for multiple comparisons.

Results

Mean age of the participants was 27.7 ± 3.8 years. The racial/ethnic makeup of the group was predominantly white (66.5%) followed by black (12.6%) and Asian (10.7%). An extensive description of the demographic composition of the subjects has been reported previously [18].

Anthropometric measurements

The average height and weight of the participants were 171.7 ± 9.5 cm and 75.1 ± 14.0 kg, resulting in an average BMI of 25.6 ± 3.9. Descriptive characteristics stratified by sex and standard BMI categories are shown in Table 1. For both women and men, the majority of participants fell within the normal BMI category with the fewest participants in the obese category. Overweight participants were on average 1.2 years older than their normal weight peers ($p = 0.009$) but the age difference between weight categories remained only significant in men ($p < 0.001$).

Table 1 Descriptive characteristics stratified by sex and weight category. Values are mean ± SD.

	Women			Men		
	Normal weight $N = 122$	Overweight $N = 56$	Obese $N = 40$	Normal weight $N = 105$	Overweight $N = 82$	Obese $N = 25$
% European American	75.4	60.7	40.0	66.7	63.4	88.0
Age (years)	27.8 ± 3.5	28.2 ± 3.8	27.6 ± 4.2	26.4 ± 3.5	28.4 ± 4.1*	29.1 ± 3.3*
Height (cm)	165.6 ± 6.5	164.2 ± 6.5	164.9 ± 6.8	179.0 ± 7.0	177.3 ± 7.2	180.6 ± 6.4
Weight (kg)	60.7 ± 6.6	74.0 ± 6.9*	87.7 ± 8.7**	73.3 ± 7.2	84.5 ± 8.3*	103.9 ± 8.1**
Body fat %	30.1 ± 6.3	39.3 ± 5.0*	43.9 ± 4.5**	16.9 ± 7.8	22.9 ± 7.4*	31.5 ± 5.3**
Total fat Mass (kg)	18.4 ± 4.8	29.2 ± 4.9*	38.5 ± 5.7**	12.4 ± 5.4	19.4 ± 6.9*	32.7 ± 6.1**
Total lean mass (kg)	39.9 ± 5.0	41.9 ± 5.3	45.6 ± 5.5**	58.3 ± 7.3	62.2 ± 7.9*	67.1 ± 7.7*,†

* $p < 0.01$ vs. normal weight.
** $p < 0.01$ vs. normal weight and overweight.
† $p < 0.05$ vs. overweight.

Average percent body fat was 35.0 ± 8.1 for women and 20.9 ± 8.4 for men with lean mass totaling 41.4 ± 5.6 kg and 60.9 ± 8.1 kg for women and men, respectively. The statistical difference among body fat percent of both women and men and across weight categories was highly significant ($p < 0.001$).

Energy intake and diet quality

Table 2 describes the daily intake of kcal by sex and BMI category. Absolute TDEI (kcal/day) ranged from 1094 to 2746, 1111 to 2882 and 1055 to 2487 kcal in normal, overweight and obese women, respectively. TDEI for normal weight, overweight and obese men ranged from 1319 to 3789, 1365 to 3936 and 1317 to 4091, respectively. While there was no difference in absolute TDEI between normal weight, overweight and obese participants, a significantly higher relative TDEI (kcal/kg/day) was observed in normal weight participants compared to their overweight and obese peers ($F_{women}(2, 209) = 36.83$, $p < 0.001$; $F_{men}(2, 200) = 15.27$, $p < 0.001$). Obese women further displayed a significantly lower HEI-2010 score compared to their peers ($F(2, 209) = 5.15$, $p = 0.007$) while there was no difference in HEI-2010 scores in men.

Energy expenditure

Energy expenditure stratified by sex and BMI category is also shown in Table 2. For women, TDEE ranged from 1714 to 3260, 1944 to 3307 and 2145 to 3241 kcal for normal, overweight and obese BMI categories respectively. Energy expenditure for the BMI categories of normal, overweight and obese for men ranged from 2233 to 4049, 2275 to 4425 and 2815 to 3831 respectively. Absolute TDEE (kcal/day) of normal and overweight men were not different while they were both lower than the TDEE of obese men ($F(2, 202) = 7.74$, $p = 0.001$). In women there was no difference in absolute TDEE between overweight and obese, but both groups had higher TDEE than normal weight women ($F(2, 210) = 21.36$, $p < 0.001$). Relative TDEE (kcal/kg/day), on the other hand, differed significantly across all groups with lower weight adjusted energy expenditure with increasing BMI in men and women ($F_{men}(2, 202) = 42.49$, $p < 0.001$; $F_{women}(2, 210) = 64.78$, $p < 0.001$).

Examining differences in energy by intensity, showed an increase in energy expenditure in sedentary time with increasing BMI ($F_{men}(2, 202) = 53.63$, $p < 0.001$; $F_{women}(2, 210) = 93.32$, $p < 0.001$) (Table 3). Overweight and obese participants also showed higher energy expenditure in light activities compared to their normal weight

Table 2 Energy intake and energy expenditure stratified by sex and weight category. Values are mean ± SD.

	Women			Men		
	Normal weight	Overweight	Obese	Normal weight	Overweight	Obese
TDEI (kcal/day)	1829 ± 502	1720 ± 433	1805 ± 377	2435 ± 705	2326 ± 708	2434 ± 914
TDEI (kcal/kg/day)	30.2 ± 7.7	23.3 ± 6.5*	20.7 ± 4.4*	33.4 ± 9.7	27.7 ± 8.4*	23.5 ± 8.9*
HEI score	63.8 ± 10.4	61.2 ± 10.6	57.7 ± 10.8*	60.3 ± 13.0	57.5 ± 1.1	55.5 ± 12.8
TDEE (kcal/day)	2280 ± 268	2485 ± 295*	2574 ± 272*	3039 ± 407	3117 ± 412	3413 ± 266**
TDEE (kcal/kg/day)	37.8 ± 4.6	33.6 ± 4.1*	29.5 ± 2.4**	41.5 ± 5.0	37.1 ± 4.4*	33.1 ± 3.0**

TDEI, total daily energy intake; HEI, Healthy Eating Index, TDEE, total daily energy expenditure.
* $p < 0.01$ vs. normal weight.
** $p < 0.01$ vs. normal weight and overweight.

Table 3 Absolute energy expenditure and rate of energy expenditure during waking hours being sedentary, in light, moderate and vigorous PA as well as in 10 min bouts of MVPA. Values are mean ± SD.

	Women			Men		
	Normal weight	Overweight	Obese	Normal weight	Overweight	Obese
Sedentary EE (kcal/day)	734 ± 101	847 ± 123*	1002 ± 115**	951 ± 140	1108 ± 167*	1300 ± 185**
Light EE (kcal/day)	528 ± 153	694 ± 193*	732 ± 188*	533 ± 172	666 ± 171*	844 ± 193**
Moderate EE (kcal/day)	497 ± 203	410 ± 234	302 ± 130*,†	871 ± 351	662 ± 323*	552 ± 294*
Vigorous EE (kcal/day)	70 ± 118	48 ± 59	32 ± 53	124 ± 146	87 ± 92	37 ± 38*
MVPA bout EE (kcal/day)	260 ± 213	151 ± 160*	84 ± 81*	509 ± 312	331 ± 255*	217 ± 228*
Sedentary EE/TDEE	41.1 ± 8.9	43.5 ± 9.7	49.2 ± 8.2**	39.6 ± 9.8	45.0 ± 10.0*	48.0 ± 8.3*
Light EE/TDEE	28.8 ± 6.8	34.5 ± 6.9*	35.0 ± 6.0*	21.6 ± 6.2	26.4 ± 5.9*	30.8 ± 6.3**
Moderate EE/TDEE	26.7 ± 8.7	19.8 ± 8.4*	14.3 ± 5.0**	34.1 ± 9.5	25.3 ± 9.2*	19.8 ± 9.5*,†
Vigorous EE/TDEE	3.4 ± 4.7	2.3 ± 2.8	1.5 ± 2.4†	4.6 ± 5.0	3.3 ± 3.2	1.4 ± 1.5*
MVPA bout EE/TDEE	13.8 ± 9.7	5.9 ± 5.6*	2.7 ± 2.6*	16.2 ± 8.3	9.0 ± 5.6*	4.7 ± 5.1*,†

* $p < 0.01$ vs. normal weight.
** $p < 0.01$ vs. normal weight and overweight.
† $p < 0.05$ vs. overweight.

peers ($F_{men}(2, 202) = 33.31$, $p < 0.001$; $F_{women}(2, 210) = 30.27$, $p < 0.001$), while energy expenditure in bouts of MVPA decreased with increasing body weight ($F_{men}(2, 202) = 14.30$, $p < 0.001$; $F_{women}(2, 210) = 16.36$, $p < 0.001$). Differences were more pronounced for energy expenditure in moderate PA ($F_{men}(2, 202) = 13.18$, $p < 0.001$; $F_{women}(2, 210) = 14.72$, $p < 0.001$) with significant differences in vigorous PA being only observed in men ($F_{men}(2, 202) = 5.45$, $p < 0.001$; $F_{women}(2, 210) = 2.73$, $p = 0.07$).

Accordingly, the proportion of energy expenditure in MPA differed significantly across weight categories in both men and women ($F_{men}(2, 202) = 33.16$, $p < 0.001$; $F_{women}(2, 210) = 36.73$, $p < 0.001$) (Table 3). Obese participants also displayed a significantly lower proportion of energy expenditure in vigorous PA but there was no difference between normal weight and overweight participants ($F_{men}(2, 202) = 6.35$, $p = 0.002$; $F_{women}(2, 210) = 4.10$, $p = 0.018$). The proportion of energy expenditure in bouts of MVPA decreased with increasing BMI in men ($F(2, 202) = 37.02$, $p < 0.001$). In women, no difference in the rate of energy expenditure in bouts of MVPA was observed between overweight and obese, but both groups displayed lower values than their normal weight peers ($F(2, 210) = 38.04$, $p < 0.001$). The contribution to TDEE in light activities was significantly increased with increasing BMI in men ($F(2, 202) = 26.64$, $p < 0.001$). Normal weight women had a significantly lower contribution of light activity to TDEE but there was no difference between overweight and obese ($F(2, 210) = 20.47$, $p < 0.001$). For sedentary behaviours, energy expenditure per TDEE was significantly higher in obese compared to overweight or normal weight women ($F(2, 210) = 12.03$, $p < 0.001$). In men the proportion of energy expenditure in sedentary time was significantly lower in normal weight compared to overweight and obese ($F(2, 202) = 10.58$, $p < 0.001$).

Adjusting for age and ethnicity did not affect the previously reported results. As shown in Fig. 1 overweight and obese adults had significantly lower weight adjusted TDEI and TDEE than their normal weight peers. No significant difference, however, was observed for weight adjusted TDEI between overweight and obese adults. The proportion of sedentary and light activities to TDEE was higher in overweight and obese, while the proportion of energy expenditure in MPA was lower in these participants. The proportion of energy expenditure in VPA did not differ between normal weight and overweight adults, but it was significantly higher compared to obese. Both, overweight and obese

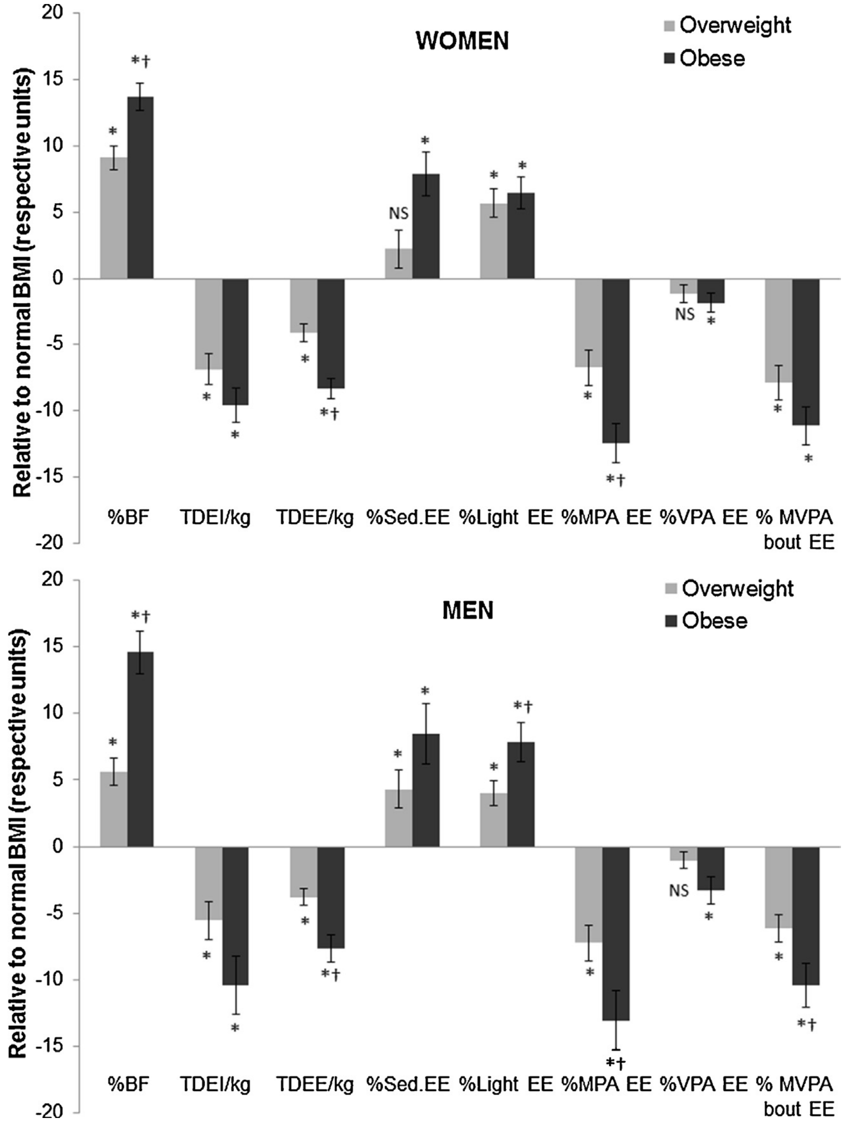

Figure 1 Difference in potential determinants of BMI in women and men, adjusted for age and ethnicity. Values are mean difference and S.E. NS, non-significant; *sig. different from normal weight; †sig. different from overweight

participants displayed a lower rate of energy expenditure in 10-min bouts of MVPA compared to normal weight participants.

Correlational analysis

Pearson's correlations for the relationships between the BMI and body fatness of women and men and potential determinants including TDEI/kg, HEI-2010, TDEE/kg and the proportion of energy expenditure in sedentary behaviours, light activities, MPA, VPA and 10-min bouts of MVPA were statistically significant at the 0.001 level (Table 4). There were, however, differences in the strength of the correlations among BMI and fatness, and correlates of energy balance. TDEE/kg had strong correlations with both BMI and body fat percent in both sexes, while for TDEI/kg the correlation was only strong with BMI in women and moderate with % body fat and BMI in men. The correlation between HEI and body composition was weak to non-existent. Strong inverse correlations were also observed between rates of MPA and BMI while the correlation between MPA and % body fat was only strong in women. Correlations between the proportion of VPA and % body fat were moderate while correlations between VPA and BMI were weak. The proportion of light energy expenditure was moderately correlated with BMI and % body fat.

Table 4 Correlation coefficients between body composition and energy intake as well as energy expenditure.

	Women		Men	
	BMI Pearson's *r*	% Body fat Pearson's *r*	BMI Pearson's *r*	% Body fat Pearson's *r*
TDEI (kcal/kg/day)	−0.533	−0.468	−0.435	−0.487
HEI score	−0.093 NS	−0.159*	−0.180**	−0.165*
TDEE (kcal/kg/day)	−0.715	−0.755	−0.577	−0.544
Sedentary EE/TDEE	0.377	0.520	0.328	0.405
Light EE/TDEE	0.440	0.396	0.471	0.358
Moderate EE/TDEE	−0.630	−0.669	−0.510	−0.452
Vigorous EE/TDEE	−0.208	−0.373	−0.258	−0.410
MVPA bout EE/TDEE	−0.593	−0.658	−0.539	−0.506

All correlations are significant at $p < 0.001$, except were noted. NS, not significant.
* $p < 0.05$.
** $p < 0.01$.

Correlations between the proportion of sedentary energy expenditure and BMI were moderate in men and women, while the correlation between % body fat and the proportion of sedentary energy expenditure was strong in women. Including only participants with complete data ($N = 407$) in the analyses did not change the previously reported results.

Discussion

The present study had a number of interesting results. Obese women and men reported a similar amount of absolute energy intake, which, when adjusted for body weight, was lower in overweight and obese compared to normal weight participants. Further, relative energy expenditure adjusted for body weight differed significantly across all BMI categories with lowest energy expenditure in obese men and women. The lower energy expenditure may be explained by a lower contribution of MVPA to TDEE in overweight and obese participants. Body weight-corrected TDEI and TDEE also had moderate to high inverse correlations with BMI and body fatness while the association between diet quality and body composition was weak. When energy expenditure was stratified by the percentage of energy expended in sedentary, light, MPA, VPA or bouts of MVPA, only MPA and bouts of MVPA showed a moderate to high inverse correlation with BMI and body fatness.

Excess body weight, lack of physical activity and the associated risk for chronic diseases have been identified as major public health problems of the early 21st century [27]. With an average weight gain in the US population of about 2 pounds of body weight or 0.2 units of BMI annually [28,29] a better understanding of the differences in energy intake and energy expenditure among different categories of body weight is of major concern. BMI, a ratio of weight to height, is the most commonly used index for classifying obesity as it relies on simple and readily available anthropometric measurements. Previous research also showed an association between BMI and disease risk [2]. BMI, however, does not consider differences in body composition and is not effective at determining fatness or fat distribution. With the likely continued broad use of BMI as the categorical index for overweight and obesity, it is important to understand the relationship among BMI, body fatness and the primary determinants of energy balance.

In the present study, results using either BMI or body fat percentage were comparable. There was an increase in energy expenditure with higher body weight and body fatness while TDEI did not differ among weight categories. Of greater interest, however, is the moderate to high inverse correlation of weight adjusted TDEE and TDEI with both BMI and body fatness. A lower weight adjusted energy expenditure has been shown previously in overweight and obese adults [30—32]. This has been attributed to lower relative energy expenditure during physical activity with increasing body weight [31,32]. The suggestion of a lower caloric intake in heavier adults may be less intuitive, but data from the National Health and Nutrition Examination Study (NHANES) also showed a lower energy intake in overweight and obese compared to normal weight adults [33]. Self-reported dietary intake data, however, has been shown to be inaccurate when compared to objective measures of dietary intake or when analysed for biological plausibility [34]. A lower energy intake per kg body weight in overweight and obese adults, nevertheless, seems plausible given the lower relative energy expenditure in these participants.

Concerning energy expenditure, there was a decline in the proportion of energy expenditure in MVPA across weight categories from normal weight to obese, while the proportion of energy expenditure in sedentary and light activities increased across weight categories. Only the percentage of energy expenditure in bouts of MVPA, however, was strongly correlated with BMI and % body fat while correlations of sedentary and light activity with BMI and % body fat were moderate. Bernstein et al. [31] also reported an increased risk for overweight and obesity with a lower rate of energy expenditure in activities above 4 METs, while associations were weaker for activities of lower intensities. Further, an inverse association between PA levels and BMI was shown using NHANES data with a stronger association between time spent in MVPA and body weight compared to less pronounced results regarding the association between sedentary time and body weight [16]. These results have been attributed to a reduced capability of participation in PA of higher intensities with higher body weight [35]. In the present study, however, only obese participants displayed a significantly lower rate of energy expenditure in VPA, which may be explained by the generally low contribution of VPA to TDEE. Taken together these findings suggest that a reduction in the ratio of energy expenditure during bouts of MVPA to TDEE is a major contributor to the lower levels of weight adjusted TDEE in overweight and obese adults. While the importance of non-exercise activity thermogenesis regarding weight gain has been previously acknowledged [36,37], results of the present study emphasise the importance of activities at moderate-to-vigorous intensities in bouts of at least 10 min regarding weight management.

Some limitations of the present study, however, need to be considered when interpreting the results. The concerns regarding self-reported energy intake have been addressed previously. Despite the accuracy of the armband in estimating energy expenditure, the generalizability of the results is limited as the study population consists predominantly of white participants with a college degree. This may also explain the lower prevalence of overweight and obesity in the study population compared to the U.S. adult population. Finally, the cross-sectional design of the study limits the inference of causality between body composition and correlates of energy balance.

Despite these limitations, results of the present study highlight the importance of achieving sufficient energy expenditure in order to facilitate energy balance at a healthy weight. Body weight corrected energy intake as well as energy expenditure decreased with increasing BMI. These results suggest that a reduction in TDEI may be less beneficial compared to increasing energy expenditure for sustainable weight loss and weight maintenance. A reduction of energy intake has actually been shown to reduce physical activity, which would hinder long-term weight loss [38]. Considering different components of TDEE, MPA and particularly bouts of MVPA displayed the strongest association with body composition. With many adults in the US and other western countries being considered to be inactive [39], increasing physical activity and energy expenditure in MVPA seems to be a major target when addressing the problem of overweight and obesity. In order to prevent weight gain, only minor adjustments in energy expenditure may be needed [40,41] while weight loss requires more efforts; perhaps also having a reduced dietary intake in addition to maintaining a high energy expenditure. More research, including longitudinal studies on potential differences in correlates of energy balance, however, is needed to increase the understanding of the regulation of energy balance in different weight categories.

Conflict of interest

The authors declare no conflict of interest.

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References

[1] Flegal KM, Carroll MD, Kit BK, Ogden CL. Prevalence of obesity and trends in the distribution of body mass index among US adults, 1999—2010. J Am Med Assoc 2012;307:491—7.

[2] Guh DP, Zhang W, Bansback N, Amarsi Z, Birmingham CL, Anis AH. The incidence of co-morbidities related to obesity and overweight: a systematic review and meta-analysis. BMC Public Health 2009;9:88.

[3] Zheng W, McLerran DF, Rolland B, Zhang X, Inoue M, Matsuo K, et al. Association between body-mass index and risk of death in more than 1 million Asians. N Engl J Med 2011;364:719—29.

[4] Finkelstein EA, Trogdon JG, Cohen JW, Dietz W. Annual medical spending attributable to obesity: payer- and service-specific estimates. Health Aff (Millwood) 2009;28:w822—31.

[5] Wang YC, McPherson K, Marsh T, Gortmaker SL, Brown M. Health and economic burden of the projected obesity trends in the USA and the UK. Lancet 2011;378:815—25.

[6] Westerterp KR. Physical activity, food intake, and body weight regulation: insights from doubly labeled water studies. Nutr Rev 2010;68:148—54.

[7] Hill JO, Melanson EL. Overview of the determinants of overweight and obesity: current evidence and research issues. Med Sci Sports Exerc 1999;31(11 Suppl):S515—21.

[8] Archer E, Shook RP, Thomas DM, Church TS, Katzmarzyk PT, Hébert JR, et al. 45-Year trends in women's use of time and household management energy expenditure. PLOS ONE 2013;8:e56620.

[9] Church TS, Thomas DM, Tudor-Locke C, Katzmarzyk PT, Earnest CP, Rodarte RQ, et al. Trends over 5 decades in U.S. occupation-related physical activity and their associations with obesity. PLOS ONE 2011;6:e19657.

[10] Kearney J. Food consumption trends and drivers. Philos Trans R Soc Lond B Biol Sci 2010;365:2793—807.

[11] Davis JN, Hodges VA, Gillham MB. Physical activity compliance: differences between overweight/obese and normal-weight adults. Obesity (Silver Spring) 2006;14:2259—65.

[12] Scheers T, Philippaerts R, Lefevre J. Patterns of physical activity and sedentary behavior in normal-weight, overweight and obese adults, as measured with a portable armband device and an electronic diary. Clin Nutr 2012;31:756—64.

[13] Strath SJ, Holleman RG, Ronis DL, Swartz AM, Richardson CR. Objective physical activity accumulation in bouts and nonbouts and relation to markers of obesity in US adults. Prev Chronic Dis 2008;5:A131.

[14] Tudor-Locke C, Brashear MM, Johnson WD, Katzmarzyk PT. Accelerometer profiles of physical activity and inactivity in normal weight, overweight, and obese U.S. men and women. Int J Behav Nutr Phys Act 2010;7:60.

[15] Yoshioka M, Ayabe M, Yahiro T, Higuchi H, Higaki Y, St-Amand J, et al. Long-period accelerometer monitoring shows the role of physical activity in overweight and obesity. Int J Obes (Lond) 2005;29:502—8.

[16] Maher CA, Mire E, Harrington DM, Staiano AE, Katzmarzyk PT. The independent and combined associations of physical activity and sedentary behavior with obesity in adults: NHANES 2003—06. Obesity (Silver Spring) 2013;21:E730—7.

[17] Westerterp KR, Plasqui G. Physical activity and human energy expenditure. Curr Opin Clin Nutr Metab Care 2004;7:607—13.

[18] Hand G, Shook R, Paluch A, Baruth M, Crowley P, Jaggers J, et al. The Energy Balance Study: The design and baseline results for a longitudinal study of energy balance. Res Q Exerc Sport 2013;84:275—86.

[19] Novotny JA, Rumpler WV, Judd JT, Riddick PH, Rhodes D, McDowell M, et al. Diet interviews of subject pairs: how different persons recall eating the same foods. J Am Diet Assoc 2001;101:1189—93.

[20] Posner BM, Smigelski C, Duggal A, Morgan JL, Cobb J, Cupples LA. Validation of two-dimensional models for estimation of portion size in nutrition research. J Am Diet Assoc 1992;92:738—41.

[21] Guenther PM, Casavale KO, Reedy J, Kirkpatrick SI, Hiza HA, Kuczynski KJ, et al. Update of the Healthy Eating Index: HEI-2010. J Acad Nutr Diet 2013;113:569—80.

[22] Johannsen DL, Calabro MA, Stewart J, Franke W, Rood JC, Welk GJ. Accuracy of armband monitors for measuring daily energy expenditure in healthy adults. Med Sci Sports Exerc 2010;42(11):2134—40.

[23] St-Onge M, Mignault D, Allison DB, Rabasa-Lhoret R. Evaluation of a portable device to measure daily energy expenditure in free-living adults. Am J Clin Nutr 2007;85:742—9.

[24] Welk GJ, McClain JJ, Eisenmann JC, Wickel EE. Field validation of the MTI Actigraph and BodyMedia armband monitor using the IDEEA monitor. Obesity (Silver Spring) 2007;15:918—28.

[25] Ainsworth BE, Haskell WL, Herrmann SD, Meckes N, Bassett DR, Tudor-Locke C, et al. 2011 Compendium of Physical Activities: a second update of codes and MET values. Med Sci Sports Exerc 2011;43:1575—81.

[26] Cohen J. Statistical power analysis for the behavioral sciences. 2nd ed. Hillsdale, NJ: L Erlbaum Associates; 1988.

[27] World Health Organization. World health report 2002: Reducing risk — promoting healthy life. Geneva, Switzerland: World Health Organization; 2002.

[28] Hill JO, Wyatt HR, Reed GW, Peters JC. Obesity and the environment: where do we go from here. Science 2003;299:853—5.

[29] Ogden CL, Fryar CD, Carroll MD, Flegal KM. Mean body weight, height, and body mass index, United States 1960—2002. Adv Data 2004;347:1—17.

[30] Ball K, Owen N, Salmon J, Bauman A, Gore CJ. Associations of physical activity with body weight and fat in men and women. Int J Obes Relat Metab Disord 2001;25:914—9.

[31] Bernstein MS, Costanza MC, Morabia A. Association of physical activity intensity levels with overweight and obesity in a population-based sample of adults. Prev Med 2004;38:94—104.

[32] Elbelt U, Schuetz T, Hoffmann I, Pirlich M, Strasburger CJ, Lochs H. Differences of energy expenditure and physical activity patterns in subjects with various degrees of obesity. Clin Nutr 2010;29:766—72.

[33] Austin GL, Ogden LG, Hill JO. Trends in carbohydrate, fat, and protein intakes and association with energy intake in normal-weight, overweight, and obese individuals: 1971—2006. Am J Clin Nutr 2011;93:836—43.

[34] Archer E, Hand GA, Blair SN. Validity of U.S. nutritional surveillance: National Health and Nutrition Examination Survey caloric energy intake data, 1971—2010. PLOS ONE 2013;8:e76632.

[35] Westerterp KR. Impacts of vigorous and non-vigorous activity on daily energy expenditure. Proc Nutr Soc 2003;62:645—50.

[36] Levine JA, Eberhardt NL, Jensen MD. Role of nonexercise activity thermogenesis in resistance to fat gain in humans. Science 1999;283:212—4.

[37] Levine JA, Lanningham-Foster LM, McCrady SK, Krizan AC, Olson LR, Kane PH, et al. Interindividual variation in posture allocation: possible role in human obesity. Science 2005;307:584—6.

[38] Redman LM, Heilbronn LK, Martin CK, de Jonge L, Williamson DA, Delany JP, et al. Metabolic and behavioral compensations in response to caloric restriction: implications for the maintenance of weight loss. PLOS ONE 2009;4:e4377.

[39] Centers for Disease Control and Prevention. State Indicator Report on Physical Activity, 2010. Atlanta, GA: U.S. Department of Health and Human Services; 2010.
[40] Hill JO, Peters JC, Wyatt HR. Using the energy gap to address obesity: a commentary. J Am Diet Assoc 2009;109:1848—53.
[41] Stroebele N, Hill JO, Willich SN. Identifying the energy gap in the German population using results from representative national health surveys (1985—2002). Public Health Nutr 2011;14:44—8.