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Associations between Multiple Indices of Energy Expenditure and Body Composition

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Abstract There has been an explosion of research investigating the association between various indices of physical activity and markers of health, including body composition, with much of this research characterized by subjective measures and single cross-sectional assessments. The purpose was to examine relationships between multiple indices of energy expenditure (EE) and body composition (BC) using objective, clinical tools in a dual cross-sectional design. Males (n=14) wore the SenseWear PRO_2 armband (SP2) for two 3-day periods (T_1, T_2) separated by 6 weeks. The SP2 measured four EE indices: total energy expenditure (TEE, kcal), physical activity energy expenditure (AEE, kcal), physical activity duration (PA, mins), and number of steps (STPS). DXA measured four BC indices: bone mineral content (BMC, g), lean soft tissue (LT, g), and adipose tissue (AT, %, g). Associations between EE and BC were examined using bivariate correlations. At T_1, TEE was correlated with BMC (r= 0.841, p<0.001) and LT (r=0.638, p=0.014), while AEE was correlated with BMC (r=0.565, p=0.035). At T_2, TEE was correlated to BMC (r=0.596, p=0.025), while AEE was associated with LT (r=0.535; p=0.049). TEE and AEE demonstrated consistent associations with fat free mass. Despite being key aspects of recommendations for health, physical activity duration and steps were not associated with any BC index nor was either index of fat mass associated with any measure of EE.

Keywords: *physical activity, fat mass, fat free mass, wearable technology*

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1. Introduction

Anthropometric measures are believed to be indirect measures of physical activity [1] and body composition is a known determinant of energy expenditure.[2] Since physical activity and body composition are well-known correlates of many chronic diseases, there has been an explosion of research investigating the association between various indices of physical activity and markers of health, including body composition. Nonetheless, associations between various anthropometrics and indices of physical activity tend to be low in the general population. [3,4]

Total energy expenditure (TEE) is an important variable to quantify accurately, given its role in weight management and disease prevention. TEE is the sum of the energy expended to support basal metabolism, physical activity, and food digestion. Physical activity energy expenditure (AEE) is the most variable of these components. While there are a number of ways TEE and AEE may be measured, research employing wearable technological devices has exploded recently. [1] There are dozens of such commercially-available devices that propose to measure energy expenditure and upon which individuals are making "life-changing decisions." [5] Given that increased AEE is means to achieve a negative caloric deficit, there is tremendous interest its quantification and a need to substantiate its associations with various indices of health to inform science and medicine. [1] Seminal research has also described its inverse association with cardiovascular death rates. [6]

To date, research has investigated relationships between various indices of physical activity and body composition in a range of populations, including children, [7,8,9] young co-ed samples, [10] older co-ed samples, [3] middle-aged females, [11,12] and African American females with a range of adiposity values. [13] Age, through its direct effects on body composition and indirect effects on physical activity, and sex are known to influence associations between physical activity and body composition, [3,4,10] posing limitations to studies using a broad range of ages and mixed sexes. Comparatively less research examining these relationships has been conducted on college-aged individuals, [14,15,16] and the physical activity behaviors of college students has been identified as a "seriously neglected" field of study. [16] Researchers have called for more research to understand energy intake and energy expenditure behaviors and patterns in this population. [14]

Previous research has employed various wearable technology devices (e.g. pedometers, accelerometers) and/or questionnaires to assess physical activity, in combination with basic, sometimes self-reported, anthropometric measures. Use of subjective measures of physical activity has been cited as a primary problem associated with research on this topic. [16] Additionally, most investigations have been single cross-sectional designs, [3,8,9,10,12,17] and it is unclear how reliable associations reported from such data may be.

The primary purposes of this investigation were to examine associations between multiple indices of energy expenditure and body composition using objective measures and determine which index of energy expenditure is more strongly and consistently associated with a given dimension of body composition. A secondary purpose was to describe aspects of energy intake.

2. Methods

2.1. Subjects

College-aged males were recruited for participation. Pre-participation screening, which included a general physical activity readiness questionnaire and health status questionnaire, revealed all participants were healthy and regular exercisers. The study was approved by the Institutional Review Board of the University of Mississippi. After explanation of all procedures, risks, and benefits, informed consent was provided by all participants.

2.2. Body Composition Assessment

Height (cm) and weight (kg) were measured using standardized procedures and a physician's scale. Dual energy x-ray absorptiometry (DXA) (Hologic Delphi-W; Bedford, MA) was used to assess indices of body composition (BC), including total body bone mineral content (BMC) (g) , lean soft tissue (LT) (g), and adipose tissue (AT) (g, %). DXA was performed at two time points (T_1, T_2) coinciding with energy expenditure and energy intake assessment.

2.3. Energy Expenditure Assessment

Energy expenditure (EE) was assessed using the BodyMedia SenseWear PRO^2 armband (SP2). The SP2 is a research-grade device worn on the superoposterior dominant arm that uses a proprietary formula to estimate EE from data derived from a pedometer, biaxial accelerometer, and three thermistors which measure environmental heat exchange and the galvanic skin response. It has been validated as a tool to assess physical activity in free-living conditions. [18] Unlike many other wearable technological devices, the SP2 does not allow users to see their physical activity data, which is worth noting to address concerns regarding the motivating nature of instant feedback from activity trackers. [19] EE was assessed over two 3-day time periods (T_1, T_2). Each of these periods consisted of one weekend day (Friday-Sunday) and two weekdays (Monday-Thursday). It has been reported that, unlike adults, adolescents and college students are less active on weekend days than weekdays. [20] The SP2 collected four mean daily indices of EE: total energy expenditure (TEE, kcal), active energy expenditure (AEE, kcal), physical activity duration (PA, mins), and number steps per day (STPS). SP2 collected data once per minute, and 2.5 METS was the threshold for AEE detection. Participants were instructed to wear the SP2 continuously for three days, except when showering and/or swimming. Each participant provided a total of six days of physical activity data.

2.4. Energy Intake Assessment

Energy intake (EI) assessment coincided with EE assessment; thus, two 3-day dietary recall collection periods were completed (T_1, T_2). Participants were provided with Nutrient Data System for Research (NDSR) dietary recall documents and instructed to record the type and amount of foods and beverages consumed. After receiving instructions on how to complete the recall documents, participants personally recorded their dietary intake for 3-days. Within 24 hours after the collection period, participants were interviewed by a dietetic professional to complete the information collection process. NDSR was utilized to analyze each participant's diet for total energy (kilocalories), protein (g, %kcal), calcium (mg), and vitamin D (μg). These nutrients were selected to examine either the adequacy of intake to support physical growth and/or due to reports of inadequate intake in this population. EE and EI data were collected as part of a larger study unrelated to energy balance. [21]

2.5. Data Analysis

Descriptive statistics were calculated for all EE, EI, and BC indices at both T_1 and T_2. Within T_1 and T_2, Pearson product-moment correlations were used to examine associations between EE and BC indices. For each BC index, pairwise correlations with each of the four EE indices were compared and tested for differences using Steiger's MULTICORR program (e.g., to test whether the correlation between BMC and TEE at T_1 was significantly different from the correlation between BMC and AEE at T_1; note that these are dependent or correlated correlation coefficients). [22] An overall test was first conducted to test whether any of the four correlation coefficients were different from one another. If this overall test was significant, individual pairs of correlation coefficients were then compared. Alpha was set a priori at 0.05, and SPSS version 22 was used for data analysis.

3. Results

A total of n=23 males participated in the study. Skin thermistors allow assessment of compliance with instructions to wear the SP2 continuously. Data from participants with an on-body SP2 duration of <75% and/or

<3 days during either T_1 or T_2 were excluded from analyses (for T_1, n=5 were excluded; for T_2, n=7 were excluded). Only data for those participants who complied with SP2 instructions at both T_1 and T_2 assessment periods were analyzed, leaving a final analysis sample of n=14. Thus, the data presented for T_1 and T_2 are from the same participants.

Participant characteristics are provided in Table 1. A paired t-test revealed no significant differences between mean body mass at T_1 and T_2 (p=0.34) or between mean BMI at T_1 and T_2 (p=0.34). The majority of the sample was Caucasian (n=12) but did include African-Americans (n=2). Descriptive statistics for EE, EI, and BC are provided in Table 2. Paired t-tests revealed no significant mean differences between any of the EE, EI, and BC variables at T_1 and T_2 (all p> 0.05).

Table 1. Participant Characteristics

Variable	Mean ±SD
Age (years)	20.86 ± 1.61
Height (m)	1.76 ± 0.08
Mass T_1 (kg)	79.51 ± 10.69
Mass T_2 (kg)	78.77 ± 9.91*
BMI_1(kg/m^2)	25.74 ± 2.80
BMI_2 (kg/m^2)	25.50 ± 2.48*

* Not significantly different (p>0.05) from corresponding variable at T1

Table 2. Energy Expenditure, Body Composition, and Energy Intake

Parameter	T1	T2
TEE (kcals)	3057.00 ± 475.37	3211.52 ± 576.34
AEE (kcals)	1066.36 ± 497.95	1273.71 ± 609.50
PA (mins)	186.29 ± 81.48	186.29 ± 81.48
STEPS (#·day)	9232.93 ± 2903.69	10940.38 ± 3907.89
BMC (g)	2906.36 ± 439.92	2872.70 ± 361.47
LT (g)	61094.16 ± 7311.59	60964.17 ± 7016.68
AT (%)	17.11 ± 5.59	17.66 ± 5.35
AT (g)	13908.99 ± 5516.79	13958.44 ± 4526.11
EI (kcals)	2474.69 ± 773.09	2463.17 ± 826.77
Calcium (mg)	967.10 ± 291.27	1004.93 ± 310.24
Vitamin D (μg)	7.06 ± 6.24	9.33 ± 11.78
Protein (g)	123.79 ± 34.61	141.79 ± 87.321

Values presented as mean ± standard deviation. TEE – total energy expenditure, AEE – active energy expenditure, PA – physical activity, BMC – bone mineral content, LT – lean soft tissue, AT – adipose tissue, EI – energy intake

The pairwise correlations between each of the four BC indices and the four EE indices at T_1 and T_2 are presented in Table 3.

Table 3. Pairwise Correlations between Energy Expenditure and Body Composition Indices

	TEE_1	AEE_1	PA_1	$STPS_1$	Differences between correlations[1]
BMC_1	0.841*	0.565*	0.238	0.481	p = 0.002 TEE_1 > AEE_1, $STPS_1$ > $STPS_1$, PA_1
LT_1	0.638*	0.247	-0.132	0.174	p = 0.009 TEE_1 > AEE_1, $STPS_1$ > $STPS_1$, PA_1
$AT(g)_1$	0.179	-0.103	-0.372	-0.104	p = 0.275
$AT(\%)_1$	0.022	-0.192	-0.414	-0.148	p = 0.505
	TEE_2	AEE_2	PA_2	$STPS_2$	Differences between correlations[1]
BMC_2	0.596*	0.512	0.309	0.293	p = 0.442
LT_2	0.500	0.535*	0.375	0.379	p = 0.291
$AT(g)_2$	0.097	-0.125	-0.433	-0.285	p = 0.178
$AT(\%)_2$	-0.086	-0.209	-0.407	-0.246	p = 0.480

[1]Based on tests of correlated correlation coefficients from Steiger's MULTICORR program. [22] P-value is from the overall test to determine if any of the four correlation coefficients are different from one another. Abbreviations on either side of > indicate significance at the 0.05 level when comparing individual pairs of correlation coefficients. For example, when examining the results from the BMC_1 row, "TEE_1 > AEE_1, $STPS_1$ > $STPS_1$, PA_1" indicates that the correlation between BMC_1 and TEE_1 (r = 0.841) is significantly greater than the correlations between BMC_1 and the other three EE indices (i.e., r = 0.565, r = 0.481, and r = 0.238); the correlation between BMC_1 and AEE_1 (r = 0.565) is significantly greater than the correlation between BMC_1 and PA_1 (r = 0.238); but the correlation between BMC_1 and AEE_1 (r = 0.565) and the correlation between BMC_1 and $STPS_1$ (r = 0.481) are not significantly different, nor is correlation between BMC_1 and $STPS_1$ (r = 0.481) significantly different from the correlation between BMC_1 and PA_1 (r = 0.238).

*Significantly different from 0 (p<0.05)

At T_1, BMC demonstrated a strong association with TEE (r=0.841, p<0.001) and moderate association with AEE (r=0.565, p=0.035). Dependent correlation coefficient tests indicated significant differences among the pairwise correlation coefficients (p=0.002) for BMC. BMC's correlation with TEE was significantly greater than its correlation with the other three EE indices. BMC's correlation with AEE was significantly greater than its correlation with PA.

At T_1, LT also demonstrated a strong association with TEE (r=0.638, p=0.014). Dependent correlation coefficient tests indicated significant differences among the pairwise correlation coefficients (p=0.009) for LT. LT's association with TEE was significantly greater than its association with the other three EE indices.

At T_2, BMC again demonstrated moderate correlations with TEE (r=0.596, p=0.025). LT was moderately associated with AEE (r=0.535; p=0.049). Dependent correlation coefficient tests indicated no significant differences among the correlations between each BC index and the four EE indices for any of the BC indices at T_2.

PA and STPS were not significantly correlated with any BC index during T_1 or T_2. Similarly, neither adiposity measure (g, %) was associated with any EE index during T_1 or T_2.

The various indices of EE generally demonstrated significant moderate to strong correlations with one another within a given measurement period (Table 4 and Table 5).

Table 4. EE Associations at T_1

	TEE	AEE	PA	STPS
TEE		0.862*	0.512	0.725*
AEE	0.862*		0.821*	0.760*
PA	0.512	0.821*		0.598*
STPS	0.725*	0.760*	0.598*	

* p<0.05

Table 5. EE Associations at T_2

	TEE	AEE	PA	STPS
TEE		0.914*	0.632*	0.650*
AEE	0.914*		0.862*	0.856*
PA	0.632*	0.862*		0.890*
STPS	0.650*	0.856*	0.890*	

* p<0.05

4. Discussion

This study is unique in that it assessed multiple objective indices of EE and BC, along with several aspects of EI, over two 3-day periods. The findings from this dual-cross sectional investigation indicate that of the four indices of energy expenditure, total energy expenditure was the index most strongly and consistently associated with indices of body composition, specifically bone mineral content and lean soft tissue. TEE demonstrated consistent associations with BMC at both T_1 and T_2; however, the significant association with LT was only seen at T_1. Active energy expenditure also demonstrated moderate correlations with bone mineral content at T_1 and lean soft tissue at T_2. Neither mean daily physical activity duration nor step total were associated with any index of body composition, nor was either adiposity measure (%, g) found to be associated with any index of energy expenditure.

Males in the current study averaged >10,000 steps per day, a value that indicates the sample was *active*. [23] Based on research to report individuals who take >9,000 steps per day are more likely to be classified as normal weight, [11,24,25] recommendations for health have recently evolved to include steps per day. [26] Despite averaging >10,000 steps per day, males in the current investigation are classified as being overweight based on its mean BMI and as having above average body fat. [27]

In the current study, BMI was classified using the approach for adults (>20 years), although three participants were 18-19 years of age. In persons <19 years, overweight and obesity are based on BMI-for-age percentile charts, while these classifications are determined in persons >20 years based on criterion values. College-aged individuals are typically 18-24 years of age, a range that includes the threshold *adult* age of 20 years. Despite the shortcomings of BMI as a tool to measure body composition (i.e., ratio of fat mass to fat free mass), DXA-derived measures of adiposity also indicated an above average body fat percent for the current sample (17.4%). [27]

In the current investigation, daily step total was not associated with any BC index at either T_1 or T_2, although relationships trended in the expected indirect direction. Significant inverse associations between steps per day and certain measures of body composition (e.g. BMI, percent body fat, waist circumference, hip circumference) have been reported in samples of older males and females. [1,11,13,25] In the college-aged population, research has reported significant inverse associations between certain indices of physical activity (steps·day^{-}1, megacounts·day^{-1}) and BMI and body fat percent in females; [10,17] however, the association was only significant for males when season was considered. [10] While accumulating a certain number of steps per day has been integrated into the cardiovascular exercise recommendations for health, results from the current study suggest its association with body composition is population-specific and may not necessarily confer a healthy body weight or composition.

In addition to steps per day, exercise guidelines for health promotion also include a recommendation for total weekly minutes of moderate and/or vigorous intensity physical activity. [28] Males in the current study averaged 197.67 minutes of physical activity per day, substantially more than the 150 minutes per week recommended by federal health agencies. While the intensity of physical activity is not known in the current study, all participants self-reported regular participation in moderate-to-vigorous structured exercise. The relative importance of total activity versus activity intensity to body composition and other measures of health has not been conclusively determined. Physical activity duration was not found to be associated with any parameter of body composition during either measurement period in the current study. Again, despite well exceeding current recommendations for physical activity duration, BMI and body fat percent were above average/normal.

Of the four EE indices measured in the current study, TEE was most strongly and consistently associated with body composition. TEE demonstrated significant correlations with bone mineral content at both T_1 and T_2 and lean soft tissue at T_1. Statistical analysis indicated the association of TEE with BMC at T_1 was significantly greater than its association with the other indices of body composition, while analyses indicated this association was not significantly different from the other pairwise comparisons at T_2. Given that TEE includes an estimate of basal metabolism and basal metabolism is influenced by the quantity of metabolically-active tissue, the relationship of TEE to these two tissues, which are both components of fat free mass, may not be surprising. It is not clear why TEE was not associated the lean soft tissue at T_2. The lack of an association of TEE with adiposity (g or %) during either T_1 or T_2 supports previous research to report a significant association between TEE and body fat percent in middle-aged (~47.5 years) females but not males. [3]

Males in the current study expended an average of 1170 kcals per day in physical activity (T_1: 1066 ± 499, T_2: 1274 ± 610) while consuming an average of 2469 kcals (T_1: 2475 ± 773, T_2: 2463 ± 827) per day. Thus, 47% of the average daily caloric intake in this sample was used to support physical activity. This amount is well above the usual estimation of 20-30%. There was a non-significant decrease in average body mass over this 6-week period. These findings provide support to the notion physical activity related energy expenditure is not related to a healthy body mass classification. [3]

Active energy expenditure was associated with both components of fat free mass; however, the associations were inconsistent. Similar to the inconsistent association of TEE with LT (i.e., at T_1 but not T_2), AEE demonstrated a significant association with bone mineral content at T_1 only and lean soft tissue at T_2 only. While the explanation for the inconsistent associations of AEE with bone mineral content and lean soft tissue is not immediately clear, it is well known that activity-related energy expenditure is the most variable component of total daily energy expenditure. While it is known AEE is the most variable component of total daily energy expenditure among individuals, the results of this study illustrate the intra-individual variation in AEE over a relatively short duration.

AEE was not associated with either adiposity measure in this population, results that are in disagreement with previous research. [3,4] Paul et al. (2004) measured TEE with doubly-labeled water or the energy intake balance method and resting metabolic rate with indirect calorimetry and defined physical activity energy expenditure as the difference between the two. Paul et al. (2004) found physical activity energy expenditure was related to body fat percent in middle-aged males but not females. Similarly, a review of 22 studies employing similar measurement techniques concluded physical activity energy expenditure was related to body fat percent in males but not females between 18-49 years of age. [4] While the difference in measurement techniques may account for the discrepancy between these previous studies and the current investigation, the SP2 has been validated against indirect calorimetry in measuring free-living physical activity energy expenditure. [18,29]

As mentioned, energy intake at T_1 and T_2 averaged 2469 kcals per day. Participants consumed on average ~1.7 g/kg of protein. Protein intake comprised ~22% of total kcals. Both of these values fall within recommended relative (g/kg) and absolute (% acceptable macronutrient distribution range) ranges. Calcium intake was nearly adequate, with an average intake of 986.02 g, which is very close to the recommended amount of 1000 mg/day. [30] Vitamin D intake was inadequate, with an average intake of 8.20 μg, well below the recommended amount of <15 μg. [30] This suggests this population could benefit from education concerning sources of Vitamin D. Although not a primary dependent variable, sleep duration was assessed. Participants averaged 383.43 ± 42.76 minutes (<6.5 hours) of sleep per day (range 4.88 – 7.48 hours), less than the 7-9 hours recommended for young adults and adults. [31]

5. Conclusion

In summary, the results of this study indicate total and active energy expenditure are associated with components of fat free mass in an active sample of young males. Of the measured indices, TEE demonstrated the strongest and most consistent associations with BMC. These results support the need for multiple cross-sectional assessments or longitudinal assessment of physical activity to characterize energy expenditure more completely and subsequently substantiate associations with parameters of body composition. Adiposity was not associated with any index of energy expenditure. Despite meeting physical activity recommendations (duration and steps per day) and expending >1,000 kcals per day in physical activity, the current sample was classified as overweight.

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