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The Relationship Among Resting Metabolic Rate and Step Counts in College Students

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THE RELATIONSHIP AMONG RESTING METABOLIC RATE AND STEP COUNTS IN COLLEGE STUDENTS

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Low resting metabolic rate (RMR) and low physical activity (PA) levels are two factors with significant impact on total daily energy expenditure (TDEE) which is one half of the energy balance equation. These two variables can lead to a positive energy balance, which over time can lead to obesity. Assessing the relationships between these variables and respiratory exchange ratio (RER) and substrate utilization is important in understanding how a balanced energy equation can be maintained long-term. **PURPOSE:** To determine the relationship among RMR, and step counts. **METHODS:** Volunteer participants ranging from 19-24 years of age (n = 26; 17 men, 9 women; 22.1 ± 1.9y) were recruited for this study. Prior to RMR testing, participants followed a protocol requiring a 6 hour fast, no exercise for 14 hours, and no alcohol or nicotine for 2 hours. Participants reclined, awake, on a padded table in a dimly lit room for 20-25 minutes while respiratory gases were measured using open-circuit spirometry. RMR, RER and substrate utilization were determined during a 5-minute period where variation in VO2 was less than 10%. Following RMR measurement, participants wore an accelerometer on their non-dominant wrist for at least 5 days. Step count data were averaged over days in which the participant had 10 hours of wear time or more. Means and standard deviations were determined for all variables. Spearman correlations were used to determine relationships among the variables. **RESULTS:** The mean RMR, step count, and RER of participants were 1789.19 ± 385.01 kcal/day, 12872 ± 3773. steps/day, and 0.88 ± 0.08, respectively. Mean substrate utilization was 45.8 ± 25.3% fat and 54.2 ± 25.3% carbohydrates. No significant relationships were found between variables aside from RER and both fat and CHO utilization ($r = -0.807$, $R^2 = 0.651$, $p < 0.001$). Correlations between other variables were not significant ($p > 0.05$). **CONCLUSIONS:** Results indicate the only relationship among variables was between RER and substrate utilization. This relationship should always exist due to substrate utilization being calculated using RER values. These results suggest that number of steps taken per day does not have a significant relationship with resting metabolism or RER. Step count may be a better indicator of TDEE than RMR due to PA's role in calculated TDEE. Further research could explore the potential relationships between RMR and other PA metrics or the relationship between TDEE and RMR.

KEYWORDS: RMR, Respiratory Exchange Ratio, RER, Substrate Utilization, Physical Activity

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B.D.H.

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CHAPTER I: INTRODUCTION

Obesity is excessive fat accumulation that causes a risk to health (World Health Organization, n.d.). Sustaining a positive energy balance causes obesity to occur in an individual (World Health Organization, n.d.). To maintain homeostasis in adipose tissue management energy intake must equal energy expenditure. This is called the energy balance equation. If an individual's energy intake exceeds energy expenditure this is called a positive energy balance. If the energy intake decreases below energy expenditure, then this is called a negative energy balance. A positive energy balance causes the individual to gain adipose tissue, which if sustained leads to obesity. A negative energy balance causes the individual to lose adipose tissue (Hill et al., 2010). The factors contributing to energy expenditure include resting metabolic rate (RMR), physical activity (PA), and the thermic effect of food (TEF). RMR is the largest factor in energy expenditure and accounts for 60-75% of total daily energy expenditure (TDEE) (McArdle et al., 2015). RMR refers to the sum of the metabolic processes of the active cell mass required to sustain normal regulatory balance and body functions during a state of rest (McArdle et al., 2015). RMR can be estimated using prediction equations. In general, all equations used to estimate RMR have a large measurement error due to the lack of any direct measurement of respiratory gases (Dunford & Doyle, 2019). Indirect calorimetry (IC) provides an accurate measure of RMR and has an advantage over room sized direct calorimeters due to the rapid response times and high degree of accuracy (Dunford & Doyle, 2019). IC measures oxygen consumption and carbon dioxide production and provides researchers with an indirect yet highly accurate estimate of energy expenditure (McArdle et al., 2015). Indirect calorimetry for RMR uses metabolic equipment to analyze the amount of oxygen consumed (VO2) and the amount of carbon dioxide produced (VCO2) while a participant lies at rest in the supine position (Blond et al., 2011).

Another factor that contributes to a positive energy balance is physical inactivity. Physical activity typically accounts for 15-30% of TDEE, although that is dependent upon how much activity is performed (McArdle et al., 2015). Individuals with low activity, or physical inactivity, will have lower TDEE and be more likely to gain excess adipose tissue than those who are more active. Unfortunately, physical inactivity in adults is an ongoing concern. According to the CDC in 2018 only 24.2% of Americans 18 years and over met both aerobic activity and muscle-strengthening guidelines (age adjusted). Additionally, 42.2% of the United States population age 18 years and older do not meet either of PA guidelines. When it comes to Americans aged 18-24 years, 33.8% meet both aerobic and muscle strengthening guidelines. Only 31.7% of this same group does not meet either PA guidelines. The percentage of Americans meeting these guidelines steadily decreases with age (National Center for Health Statistics (U.S.) & Gindi, 2021). This indicates that as the United States population ages they are less likely to be meet PA guidelines, highlighting the importance of physical activity intervention with young adults to promote sustainable healthy PA habits.

One metric that can be easily used to measure PA levels is step count. According to a 2011 study on daily step counts, it appears that healthy adults can take anywhere between approximately 4,000 and 18,000 steps/day, and that 10,000 steps/day is a reasonable target for healthy adults (Tudor-Locke et al., 2011). When comparing adults who took 4,000, 8,000, and 12,000 steps per day studies have shown that taking more than 4,000 steps per day leads to a lower risk of death over the course of 10 years. Compared to the adults who took 4,000 steps per day adults who took 8,000 steps had a 50% lower risk of dying. Adults who took 12,000 steps per day had a 65% lower risk of death when compared to the same 4,000 step group (Saint-Maurice et al., 2020). By targeting 10,000 steps per day, even when falling 2,000 steps short of the goal adults can decrease their risk of death in the next 10 years by up to 50%. This shows that increased daily PA in the form of steps has a positive effect on adult's health.

There have not been any known studies conducted examining the relationship of RMR and PA using step count as the PA metric. We hypothesized that there would be a positive relationship between RMR and step count. This was hypothesized due to the suggested relationship between PA and resting metabolism discussed by McArdle (McArdle et al., 2015). Further research on PA and RMR indicates habitual PA and RMR have a statistically significant relationship (Gilliat-Wimberly et al., 2001). However, this research used hours of PA per week to measure participant PA. Mode of PA in Gilliat-Wimberly was not consistent among participants.

The thermic effect of food (TEF) is the last factor that contributes to TDEE. TEF is the increase in energy expenditure due to food consumption (Dunford & Doyle, 2019).TEF also has the smallest effect on an individual's TDEE, accounting for approximately only 10% of TDEE (McArdle et al., 2015). TEF can be measured by using IC to measure energy expenditure. Energy expenditure is measured for 10 minutes every 30 minutes for the subsequent 6 hours after food consumption. Then the baseline RMR measurement is subtracted from this energy expenditure to isolate energy expenditure from food (Reed & Hill, 1996). Factors such as meal size, meal composition, the nature of an individual's diet, insulin resistance, PA, and ageing all influence TEF (de Jonee & Bray, 1997). Additionally, a critical review by Jong and Bray found that 22 out of 29 studies found that TEF was reduced in individuals with obesity. This review suggested that the greater degree of insulin resistance the smaller the TEF (de Jonee & Bray, 1997).

There is a gap in research literature when it comes to RMR and the relationships it has with step count, RER, and substrate utilization. This study will fill that gap in research by providing useful information about these relationships. We hypothesized that there would be a positive relationship between RMR and step count in individuals. Research about these potential relationships could be beneficial in preventing obesity in the college aged population. Forming these health habits in early adulthood is important to do before TDEE decreases and a balanced energy equation becomes more difficult to maintain.

CHAPTER II: METHODS

Sample

The target population of this study was generalized to college-aged adults. A total of 26 college-aged adults (17 men and 9 women) aged 19 - 26 years participated in the study. These participants were recruited from Illinois State University. The Institutional Review Board (IRB) reviewed and approved the study procedures. Informed consent was obtained from all participants.

Procedures

Data collection sessions were scheduled for 1 hour but typically lasted 30-45 minutes. First, the participants were given the informed consent to read and sign. Then, participants were asked if they consented to each measurement taken and were given the option of knowing their results or not being told. Next, participant's mass and height were measured. After the anthropometric measures, the participant was fitted with a heart rate monitor and a V2 mask for RMR assessment. Last, after the RMR assessment participants were given the Actigraph accelerometer. The accelerometers were returned one week later, and participants were sent a clinical report containing their PA data if they desired.

Anthropometric Measurements

Standing height was measured to the nearest 0.1 cm using a stadiometer with a vertical backboard and headpiece. Body mass was measured to the nearest 0.1 kg on a digital weight scale. Participants removed shoes prior to all anthropometric measurements.

Metabolic Measurement

Resting metabolic rate was measured with indirect calorimetry using a metabolic cart (COSMED QUARK). A 28mm turbine was used along with reusable silicon rubber COSMED

V2 masks and disposable viral filters. Metabolic cart calibration was completed prior to participants' arrival and was completed again if any participants were tested four hours or more after initial calibration. Participants were fitted with masks prior to completing a 5-minute rest period lying in the supine position in a quiet dark room. Data collection was started at the end of the rest period with the first 5 minutes of data being discarded. This allowed for the full 10 minutes of rest prior to data collection and allowed heart rate, VO2, and VCO2 to be monitored prior to official data being collected. RMR test was ended after 16 minutes to allow for a full 10 minutes of data to be collected. Participants were not permitted to fall asleep during assessment. After discarding the initial 5 minutes, the data were analyzed to identify a 5-minute period from the remaining time with the lowest percentage of variance. Participants with a VO2 variance greater than 10% were excluded from the study (Compher et al., 2006). This 5-minute segment was used for the official RMR measurement. Participants verbally verified adherence to the pre-test protocol. Pre-test protocol consisted of abstaining from moderate physical activity for 2 hours, abstaining from vigorous resistance training for 14 hours, fasting for 6 hours, abstaining from caffeine overnight, and abstaining from nicotine and alcohol for 2 hours prior to the measurement (Compher et al., 2006).

Physical Activity Measurement

PA was measured using the Actigraph GT9X Link accelerometer (Pensacola, FL). The accelerometer uses a gyroscope, magnetometer, and secondary accelerometer to collect information on participant's movement, rotation, and body position. This information was used to measure steps taken and energy expended through PA. Actilife software version 6.13.4 was used for initialization, downloads, and exportation of collected data. Initialization is the process of preparing the accelerometers to collect data for the given participant. Participant's height, weight, date of birth, ethnicity, dominant hand, and wrist were documented during initialization process. The accelerometers were initialized at a sampling rate of 30 Hz, this means they collected data at a frequency of 30 times per second. Once the accelerometer was initialized participants were asked to wear it on their non-dominant wrist for five consecutive days (with at least one weekend day in that range). Participants were not provided with any feedback from the Actigraph monitor and so could only see a blank screen. A minimum of 10 hours per day on at least two weekdays and one weekend day were required to be part of the analysis, otherwise those days not meeting criteria were excluded (Rich et al., 2013). Sleep time was subtracted from wear time to accurately assess minutes of wear time per day. After the 5-day period ended participants returned accelerometer for data to be downloaded and exported.

Statistical Analysis

Collected data were analyzed with SPSS statistical software, version 28. Means and standard deviations were calculated for all variables. Spearman correlations were calculated to determine the relationships between variables.

CHAPTER III: RESULTS

Descriptive statistics for both men (n = 17) and women (n = 9) are presented in Table 1 as means/standard deviations. From the total sample (n = 26), 65.4% of participants were men and the remaining 34.6% were women. The average age of participants was 22.1 years with a slightly higher average age for men (22.2 years) and a slightly lower average age for women (22 years). The sample had an average mass of 88.7 kg. Average mass of participants by sex was 98.1 kg for men and 71 kg for women.

The average measured RMR for the total sample was 1789 ± 385 kcal/day. The average RMR for men was higher than the sample average at 1,992 ± 277 kcal/day. Average RMR for women was lower than the sample average at 1,406 ± 239 kcal/day.

Results for the sample average RER during RMR measurement was 0.88 ± 0.08, with a substrate utilization of 45.8 ± 25.3% fat and 54.2 ± 25.3% CHO. Men had an average measured RER of 0.89 ± 0.09, substrate utilization for men consisted of 41.3 ± 26.3% fat and 58.7 ± 26.3% CHO. The average RER for women was 0.87 ± 0.07 with a substrate utilization breakdown of 54.2 ± 22.2% fat and 45.8 ± 22.2% CHO.

The sample average steps taken per day was 12,872 ± 3,773 steps. Men took an average of 12,892 ± 3,773 steps while women took an average of 11,403 ± 1845 steps. Means and standard deviations were also calculated separately for weekdays and weekends. Average weekday step count was 12,636 ± 3,682 steps while the average weekend day step count was 13,474 ± 7,235. Figure 1 displays the average step count for average daily, average weekday, and average weekend day for the total sample.

Spearman correlations between variables found that aside from RER and substrate utilization data ($p < 0.001$), relationships among all variables were not statistically significant (p

> 0.05). Correlation coefficients are presented for each variable in table 2. The relationship between RMR and step count is demonstrated in Figure 2.

Means and standard deviations were also calculated for sleep data. Mean sample wear time was 294.15 ± 91.79 minutes per night (4.9 ± 1.5 hours). One participant had zero minutes of sleep time, as they did not wear the accelerometer to sleep. This individual was excluded from the sample average sleep time.

Table 1. Descriptive Characteristics

	Total (n=26)	Men (n=17)	Women (n=9)
Age (years)	22.1 ± 1.9	22.2 ± 2.2	22.0 ± 1.4
Height (cm)	175.9 ± 11.8	181.9 ± 8.5	164.5 ± 8.5
Mass (kg)	88.7 ± 27.2	98.1 ± 26.6	71.0 ± 18.8

Table 2. Correlation Coefficients

	RMR	RER	% Fat	% CHO	Average Steps/Day
RMR		0.87	-0.183	0.183	-0.106
RER	0.87		0.807**	-0.807**	-0.204
% Fat	-0.183	0.807**		1	0.121
% CHO	0.183	-0.807**	1		-0.121
Average Steps/Day	-0.106	-0.204	0.121	-0.121	

** Correlation is significant at the 0.01 level

Figure 1. Average Step Counts

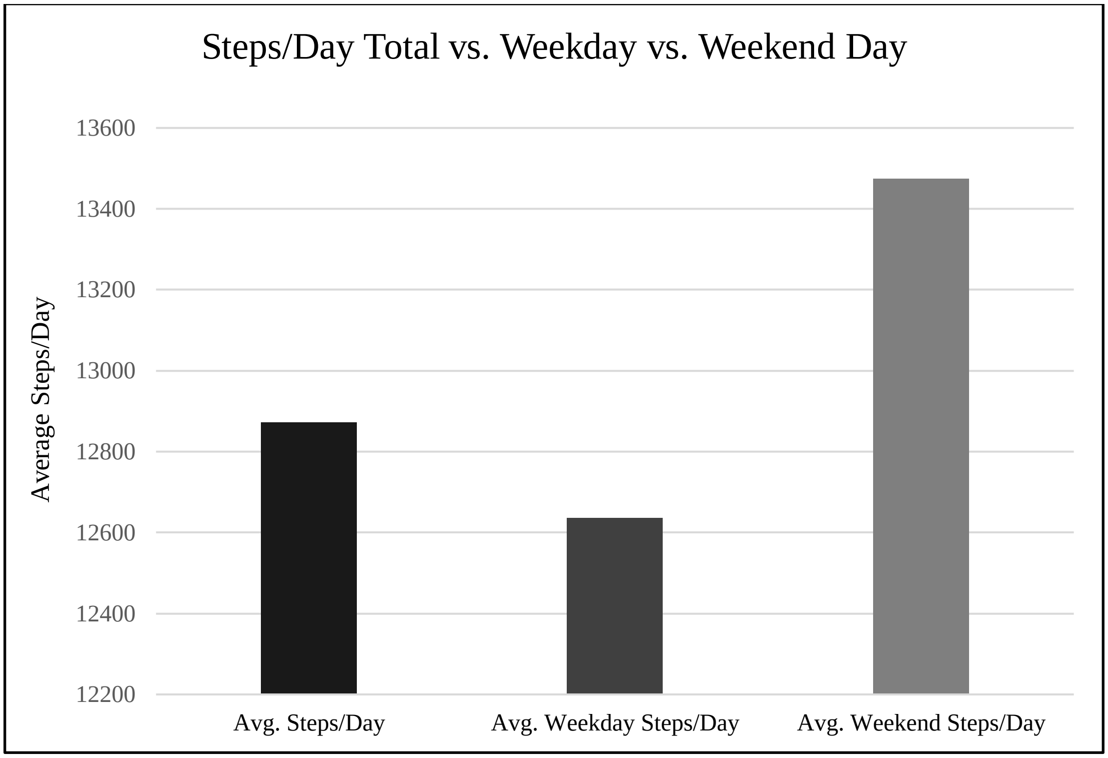
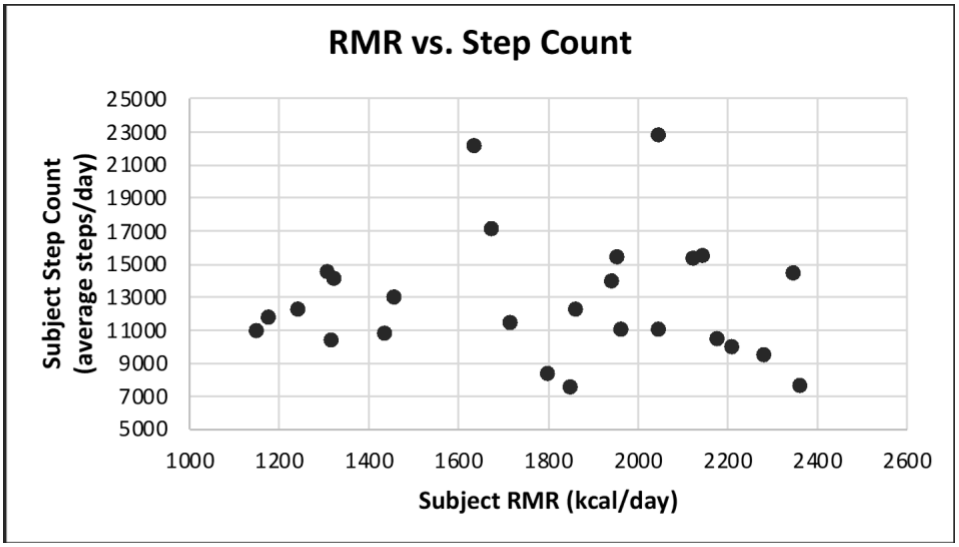


Figure 2. RMR vs. Step Count



CHAPTER IV: DISCUSSION

The aim of this study was to investigate the relationships among RMR, RER, substrate utilization, and step count in college aged individuals. We hypothesized that there would be a positive relationship between RMR and step count. This was hypothesized due to the suggested relationship between regular PA and resting metabolism. McArdle et al., have indicated that regular PA appears to affect resting metabolism as well as other factors such as body composition. This relationship between regular PA and RMR originates from studies on older individuals participating in exercise training (Hendrickson, 1975; Speakman & Selman, 2003). The current study utilized step count as an indicator of regular PA in order to determine if there was also a relationship between RMR and daily steps taken. No relationship between RER and RMR or RER and step count was hypothesized because prior research has indicated that resting RER depends on variables not included in this study. These variables were determined to be muscle glycogen content, training volume, proportion of type 1 fibers, and diet (Goedecke et al., 2000). We also hypothesized RER to have a positive relationship with percent CHO and a negative relationship with percent fat. Results of this study found no statistically significant relationship between RMR and step count, or any other variables aside from RER and substrate utilization. The relationship between RER and substrate utilization was previously expected due to the use of RER to calculate substrate utilization.

Prior studies on physical activity and RMR have suggested that individuals who participate in habitual PA record a higher RMR rate when compared to more sedentary individuals. Gilliat-Wimberly et al. looked into the effects of habitual physical activity on RMR and body composition of women aged 35 to 50 years. In this study the habitually active group consisted of women who get at least 6 hours of exercise per week. The sedentary group consisted of women who exercise less than 2 hours per week. Both groups have maintained their current PA level (Habitually active or sedentary) for at least 5 years. This research found that participants in the habitually active group had lower body fat mass and percent body fat while maintaining a higher RMR. Average RMR of the habitually active group was 1,510 kcal/day while the sedentary group average was 1,443 kcal/day. This may not be a large difference, but when RMR is adjusted for participants fat free mass (FFM) the difference was statistically significant ($p = 0.045$). Some differences between this study and ours that could explain the difference in results are that the Gilliat-Wimberly et al. study adjusted RMR for FFM, used hours of PA per week as a PA metric, and consisted of an older sample of only women. The most likely cause of difference is the lack of adjustment for FFM with our RMR measurements. This indicates that potential further studies could measure body composition and adjust RMR for FFM to retest our hypothesis (Gilliat-Wimberly et al., 2001).

Prior research of RMR has indicated that sleep restriction leads to lower measured RMR values compared to a control group with unrestricted sleep (Spaeth et al., 2015). In this study the sample consisted of healthy adults split into a sleep restricted group and a control group. The restricted group slept 4 hours per night for 5 nights followed by a one night 12-hour recovery sleep. The control group slept for 10 hours each night. Results of this study were that the restricted groups RMR decreased (-2.6%, $p = 0.032$) and returned to baseline after the recovery sleep. This study identifies sleep as one factor that may have caused a lack of relationship between variables in our study. The accelerometers worn by participants in our study had a sleep tracking feature. All participants but one wore the accelerometer during sleep. The average sleep time per night was 4.9 ± 1.5 hours per night. This indicates our sample could be classified as sleep restricted. Future research could control for sleep in the study to account for potential error in RMR caused by sleep restriction.

One other potential explanation for the lack of significant relationship among RMR and step count could be that step count is not an accurate representation an individual's total PA habit and does not gather intensity of activity. Step count as a metric reflects incidental PA throughout the day but does not always reflect of total daily PA. Previous studies have shown that individuals who engage in regular moderate to vigorous PA have a higher RMR (Woods et al., 2018). This may indicate that gathering intensity levels of daily PA routines could be better to explain the relationships between RMR and PA.

This study does have its limitations, starting with the adherence of a pre-test protocol necessary for an accurate measurement of resting metabolic rate. While McArdle indicates that indirect calorimetry is an accurate means of measuring resting metabolic rate, these tests do rely on the participant's ability to adhere to pretest protocols to collect an accurate measurement (Compher et al., 2006). These pretest protocols can be difficult for some individuals to follow. The protocols include abstaining from moderate physical activity for 2 hours, abstaining from vigorous resistance training for 14 hours, fasting for 6 hours, abstaining from caffeine overnight, and abstaining from nicotine and alcohol for 2 hours prior to the measurement (Compher et al., 2006). This mandatory protocol was followed the night prior to and the morning of data collection with no supervision of participants to ensure adherence. To mitigate the risk of participant non-compliance each volunteer consented to the protocol prior to testing, and verbally confirmed adherence before the RMR assessment started. Additionally, this study does not control for the variable of sleep. According to the research performed by Spaeth et al. that was previously discussed, lack of sleep can have a significant impact on RMR measures. Due to the average sleep time of the sample, lack of control for this variable could influence RMR validity. Strengths of this study include the use of a tri-axial accelerometer to assess step count. The tri-axial accelerometers are an advantage because they measure movement in three planes instead of just one plane (Tudor-Locke et al., 2002). Due to this, they capture more movement and get a more accurate step count than a pedometer. These accelerometers also did not display data to participants in order to prevent changes in PA habits due to knowledge of step count. The use of 10 hour cut points for step count ensured participants wore the accelerometers long enough to represent daily physical activity (Rich et al., 2013). The 10% VO2 variance cut point for RMR assessment strengthened the validity of the RMR values. The use of our pre-test protocol eliminated concerns of the thermic effect of food, caffeine, nicotine, alcohol, or exercise having any impact on RMR measures.

CHAPTER V: CONCLUSIONS

PA has been shown to play an important role in weight management when considering the energy balance equation. PA was hypothesized to have an even larger effect on the energy balance equation if a relationship was found between RMR and PA. A statistically significant relationship between these two variables was not found in this study. This indicates the role PA plays on the energy balance equation may be limited to TDEE when PA is measured using step count. However, prior studies have found a relationship between RMR and habitual PA when RMR values are adjusted for fat free mass of the individuals. This indicates future research could be done to determine the relationship between step count and RMR adjusted for FFM. Prior studies also point to sleep restriction impacting RMR measures. Future research could measure sleep of participants to account for this or use a different sample with less of a risk of sleep restriction to avoid potential error in RMR measures.

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