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Differences in Body Fat in Athletes Categorized by Resting Metabolic Rate

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Abstract: The purpose of the study was to examine differences in body fat percentage (BF%) across groups stratified by resting metabolic rate (RMR) when normalized to body weight. National Collegiate Athletic Association Division III athletes (n = 190; Age: 19.8 ± 1.4 year; Body Mass: 79.3 ± 20.2 kg; Height: 175.0 ± 9.3 cm, Body Mass Index: 25.6 ± 4.9 kg/m^2) participated in this cross-sectional mixed cohort study. Body composition was assessed using air displacement plethysmography. RMR was assessed using indirect calorimetry. For each sex, tertiles were determined and used to create low, moderate, and high relative RMR groups as follows: low (M: <26 kcal/kg; F: <24 kcal/kg), moderate (M: 26.1–29.0 kcal/kg; F: 24.1–27.0 kcal/kg), and high (M: >29.1 kcal/kg; F: >27.1 kcal/kg). The mean ± standard deviation RMR for male and female athletes was 27.9 ± 3.2 and 25.9 ± 2.8 kcals/kg when expressed relative to body weight. When stratified by sex, males in the low RMR group had significantly higher BF% values than those in the moderate (mean difference, [95% confidence intervals]) (7.2, [2.4, 12.0] kcal/kg; $p < 0.01$) and high RMR groups (7.7, [2.9, 12.5] kcal/kg; $p < 0.001$). Female athletes in the moderate RMR group had higher body fat percentages than those in the high RMR group (mean difference, [95% confidence intervals]) (5.8, [2.4, 9.2] kcal/kg; $p < 0.01$). Female athletes in the moderate relative RMR group had higher BF% values than those in the higher relative RMR group (3.3, [−0.1, 6.7] kcal/kg; p = 0.049). Both male and female athletes with a low relative RMR had a higher BF%.

Keywords: metabolism; body composition; sports; body mass; metabolic adaptation

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1. Introduction

Resting metabolic rate (RMR) accounts for 40–60% of total daily energy expenditure (TDEE), and therefore plays a pivotal role in energy balance for athletes [1]. Day-to-day changes in energy balance are a key driver for subsequent changes in body weight and body composition [1]. A higher daily TDEE could alter daily energy balance in a way that promotes weight loss, namely fat loss, assuming energy intake remains unchanged or below that of TDEE [2]. Conversely, a lower TDEE may predispose athletes to weight gain and subsequently increase body fat accumulation over time if energy intake is not carefully managed [2,3]. As such, an athlete's RMR plays a key role in weight management over time.

While the assessment of RMR is common across the literature, limited information is available regarding the classification of an athlete's RMR and how it may influence body composition parameters, such as body fat percentage. Expressing RMR relative to body mass may serve as a way to categorize an athlete's RMR and help provide context when interpreting values for athletes. Additionally, normalized RMR values allow for more appropriate comparisons between athletes, as body size (i.e., body weight) accounts for a substantial degree of variation in RMR [4].

The expression of RMR relative to body weight may also help when examining relationships between metabolic activity and body composition, as it accounts for differences in body weight. For example, an athlete with a high RMR, when expressed relative to body weight, may exhibit a lower body fat percentage due to a higher TDEE. Additionally, this could predispose an athlete to be a 'hard-gainer' if there is a desire for weight gain or the accrual of fat-free mass (FFM) in training. Furthermore, athletes with a low body fat percentage may require additional increases in energy intake to compensate for a higher RMR, relative to body weight, if attempting to increase body mass. Conversely, previous research has indicated that a low body fat percentage, often a result of a prolonged energy deficit, may result in numerous physiological and metabolic adaptations, which may suppress energy expenditure as a reflection of improved metabolic efficiency and compensate for low energy intake [5,6]. Therefore, athletes with a lower body fat percentage may exhibit lower, or suppressed, RMR values, even after accounting for differences in body mass and FFM. However, a lower body fat percentage would also indicate a higher percentage of FFM for a given athlete. FFM has been previously shown to be a strong predictor of RMR in athletes, often accounting for 70% of the variance in RMR [7]. Therefore, athletes with a higher percentage of FFM or greater overall FFM will likely have higher RMR values, when expressed relative to body mass, when compared to their counterparts with less FFM [4,7,8]. Currently, it is unknown how RMR and various expressions of RMR (e.g., RMR/kg, RMR/kg of FFM) among athletes could be categorized and what level of influence these values may have on body fat percentages.

We have previously reported that RMR is higher in male athletes compared to female athletes, largely mediated by greater absolute body mass in male athletes [4,9]. Further, when expressed relative to body mass and FFM, differences in RMR initially observed between male and female athletes become insignificant [4,9]. Additionally, strong relationships between body mass and RMR, and FFM and RMR [4,7–14], for both male and female athletes have been previously observed. However, more work is needed to categorize RMR values across male and female athletes and examine how this may influence body composition. Additionally, a descriptive summary of RMR values expressed relative to body mass can allow practitioners to better interpret RMR values and classify athletes as having a 'low' or 'high' RMR and allow for the comparison of body composition parameters (e.g., body fat percentage) between athletes. Therefore, the current study aimed to examine differences in body fat percentage between individuals grouped by relative RMR. A secondary aim was to propose ranges of relative RMR values to allow for the classification of RMR, after accounting for differences in body weight.

2. Materials and Methods

2.1. Subjects

National Collegiate Athletic Association Division III male (n = 98) and female (n = 92) athletes representing multiple sports volunteered to participate in this study (Table 1). Participants were eligible to participate in the study if they were medically cleared to participate in their sport. Exclusion criteria included current injury that prevented sport participation, or a recent diagnosis of a cardiac, respiratory, circulatory, autoimmune, musculoskeletal, metabolic, hematological, neurological, or endocrine disorder or disease. Athletes from the same NCAA Division III institution were recruited to participate in the study. Athletes provided self-reported weekly training volume at the time of testing (Table 1). Athletes were informed of the risks and benefits associated with participation, and signed a written informed consent. All procedures involving human subjects were conducted in accordance with the requirements of the Declaration of Helsinki and approved by an Institutional Review Board (IRB #19-707 on 11 March 2019). Trained research personnel conducted data collection according to standard laboratory practices. A priori analysis determined a total sample size of 66 participants would be needed to detect an effect size of 0.4 for differences in BF% between groups with 80% power and alpha of $p < 0.05$.

Table 1. Physical characteristics of subjects.

	Male (n = 98)	**Female (n = 92)**
Age (years)	20.1 ± 1.6	19.4 ± 1.1
Body Mass (kg)	92.7 ± 17.5	65.2 ± 11.0
Height (cm)	181.6 ± 6.2	168.0 ± 6.6
BMI (kg/m^2)	28.0 ± 4.7	23.0 ± 3.6
Body Fat (%)	15.6 ± 8.8	22.7 ± 6.0
Fat-free Mass (kg)	77.1 ± 9.4	49.6 ± 6.4
Sport	XC: 5 (5%) T&F: 6 (6%) BASE: 8 (8%) FB: 62 (63%) WRES: 17 (17%)	XC: 9 (10%) T&F: 23 (25%) DIVE: 2 (2%) SOC: 43 (47%) SWIM: 4 (4%) TEN: 2 (2%) VB: 9 (10%)
Training Volume (h/week)	7.7 ± 4.7	9.4 ± 3.1

Values are mean ± SD and n (%). BMI: body mass index; BASE: baseball; XC: cross country; FB: football; T&F: track and field; WRES: wrestling; DIVE: diving; SOC: soccer; SWIM: swimming; VB: volleyball; TEN: tennis.

2.2. Study Design

Data were collected during the competitive seasons between 2016 and 2019. Athletes participated in this cross-sectional cohort study and reported to the laboratory for testing within the first 6 weeks of the competitive season. Data were collected in one laboratory visit between the hours of 6:00–10:00. Athletes completed a body composition assessment, followed by an RMR test in a climate-controlled laboratory setting (temperature range: 22–24 °C, and relative humidity range: 37–44%). Participants were instructed to report to the laboratory in a fasted (>12 h) and hydrated state, and to refrain from strength training, conditioning, and sport-specific practice sessions conducted at greater than 50% effort for <24 h prior to testing.

2.3. Procedures

2.3.1. Resting Metabolic Rate

RMR assessments were conducted using indirect calorimetry (ParvoMedics TrueOne 2400 Metabolic System, Salt Lake City, UT, USA). Participants were instructed to remain motionless in a supine position on an exam table for approximately 20 min prior to the start of testing. Resting oxygen uptake was determined using a clear, hard plastic hood and soft, clear plastic drape placed over the participant's neck, head, and shoulders to determine energy expenditure. Participants were instructed to remain awake and motionless throughout the duration of the 15-min testing period. A five-minute period was analyzed in which criterion variables (e.g., VO_2 L/min) did not vary by more than 5%. Oxygen uptake and carbon dioxide production was used to calculate RMR using the Weir equation [15] and expressed as kilocalories (kcal) per day. The TrueOne 2400 indirect calorimeter has been previously shown to provide valid and reliable measures of O_2 and CO_2 when compared to methanol combustion techniques [16], with relative percent errors of −0.653% and −0.525%, respectively, and a coefficient of variation of 1.56% for test-to-retest reliability.

2.3.2. Body Composition

A Seca® physician's scale and stadiometer were used to determine body mass and height per standard clinical procedures. Air displacement plethysmography (BODPOD, Cosmed, Concord, CA, USA) was used to assess body composition for the determination of body fat and fat-free mass (FFM). Prior to each testing session, calibration procedures were completed in accordance with manufacturer guidelines using a calibration cylinder of a standard volume (49.55 L) and an empty chamber. Participants were instructed to wear a formfitting sports bra (females), spandex shorts, and swim cap, and remove all jewelry, in accordance with standard operating procedures to reduce air displacement. Manufacturer default settings were used to predict thoracic gas volumes for each participant. Fat mass and FFM were then determined based on the participant's body mass and measured body volume using the Brozek equation [17]. Test-to-test reliability in our lab is high for BM (r = 0.999), body fat percent (r = 0.994), and FFM (r = 0.998). Male and female athletes were stratified into groups based on relative RMR values. For each sex, tertiles were determined as used to create low, moderate, and high relative RMR groups as follows: low (M: <26 kcal/kg; F: <24 kcal/g), moderate (M: 26.1–29 kcal/kg; F: 24.1–27 kcal/kg), and high (M: >29.1 kcal/kg; F: >27.1 kcal/kg).

3. Statistical Analysis

A 2-way mixed factorial analysis of variance was used to examine between-group differences for sex (males vs. females) and relative RMR groups (low, moderate, high). Tukey post hoc test was used if significant differences were identified. Pearson correlation coefficients were used to examine relationships between BF% and body mass, FFM, RMR, RMR/kg, and RMR/kg of FFM. The strength of correlation coefficients was classified as trivial ($|r| < 0.10$), weak ($0.10 \leq |r| < 0.30$), moderate ($0.30 \leq |r| < 0.50$), strong ($0.50 \leq |r| < 0.70$), very strong ($0.70 \leq |r| < 0.90$) and nearly perfect ($r \geq 0.90$) [18]. Further, linear regression analysis was used to determine which predictor variables (body mass, fat-free mass, RMR/kg, RMR/kg of FFM) best predicted BF%. The standard error of estimate (SEE) was determined to help evaluate the fit of the regression model for the BF% values. The Shapiro–Wilk test was used to confirm normality of all variables. Statistical analyses were conducted using the IBM SPSS Statistics for Windows (version 25.0; IBM Corp., Armonk, NY, USA). Significance was determined at $p < 0.05$.

4. Results

The mean ± standard deviation RMR for male and female athletes was 27.9 ± 3.2 and 25.9 ± 2.8 kcals/kg when expressed relative to body weight. A summary of percentiles for relative RMR values across male and female athletes is presented in Table 2. There was no significant sex by group interaction effect observed for BF% ($p = 0.273$). A main effect of sex was observed for relative RMR ($p < 0.001$), as males had a lower BF% (mean difference, [95% confidence intervals]) compared to females (−6.9, [−8.9, −4.9%]). There was a significant group effect in which athletes in the low relative RMR group had higher BF% values compared to those in the moderate (5.2, [2.2, 8.2%]) and high (6.7, [3.6, 9.7%]) relative RMR groups.

Table 2. Percentiles for relative resting metabolic rate.

		5	**10**	**25**	**50**	**75**	**90**	**95**
RMR (kcal/kg)	Males	22.6	23.2	25.4	28.1	29.9	32.8	33.5
	Females	21.9	22.6	24.0	25.5	28.0	29.7	31.4

RMR = resting metabolic rate; kcal/kg = kilocalories per kilogram.

4.1. Male Athletes

When stratified by sex, there were significant differences ($p < 0.05$) in BF% across RMR groups as summarized in Table 3. Male athletes in the low relative RMR group had significantly higher BF% values than those in the moderate (mean difference, [95% confidence intervals]) (7.2, [2.4, 12.0] kcal/kg; $p < 0.01$) and high relative RMR groups (7.7, [2.9, 12.5] kcal/kg; $p < 0.001$).

Table 3. Summary of body fat percentage and body weight across groups.

	Group	*n*	Body Fat (%)	Body Weight (kg)	BMI (kg/m^2)
Males	Low (<26 kcal/kg)	32	20.7 ± 9.1 *	103.6 ± 18.8 *	30.9 ± 4.8 *
	Moderate (26.1–29 kcal/kg)	32	13.5 ± 5.8	88.7 ± 14.4	26.9 ± 4.2
	High (>29.1 kcal/kg)	34	13.0 ± 9.0	86.1 ± 14.1	26.2 ± 3.6
	p value		<0.001	<0.001	<0.001
Females	Low (<24 kcal.kg)	30	25.5 ± 7.4 *	71.6 ± 12.8 *	25.2 ± 4.7 *
	Moderate (24.1–27 kcal/kg)	31	23.0 ± 4.3 #	63.3 ± 8.9 #	22.7 ± 2.4
	High (>27.1 kcal/kg)	31	19.7 ± 4.5	60.8 ± 8.1	21.3 ± 1.8
	p value		<0.001	<0.001	<0.001

Data presented as mean ± standard deviation. BMI = body mass index; RMR = resting metabolic rate; kg = kilograms. * Denotes significant difference between low and high relative RMR groups ($p < 0.05$). # Denotes significant difference between moderate and high relative RMR groups ($p < 0.05$).

4.2. Female Athletes

There were significant differences ($p < 0.05$) in BF% across RMR groups, as summarized in Table 3. Female athletes in the low relative RMR group had significantly higher BF% values than those in the high relative RMR group (mean difference, [95% confidence intervals]) (5.8, [2.4, 9.2] kcal/kg; $p < 0.01$). Female athletes in the moderate relative RMR group had higher BF% values than those in the high relative RMR group (3.3, [−0.1, 6.7] kcal/kg; $p = 0.049$).

A weak relationship between BF% and body weight (r = 0.162; $p = 0.026$) was observed (Figure 1A). A very strong relationship existed between FFM and body weight (r = 0.828; <0.001) (Figure 1B).

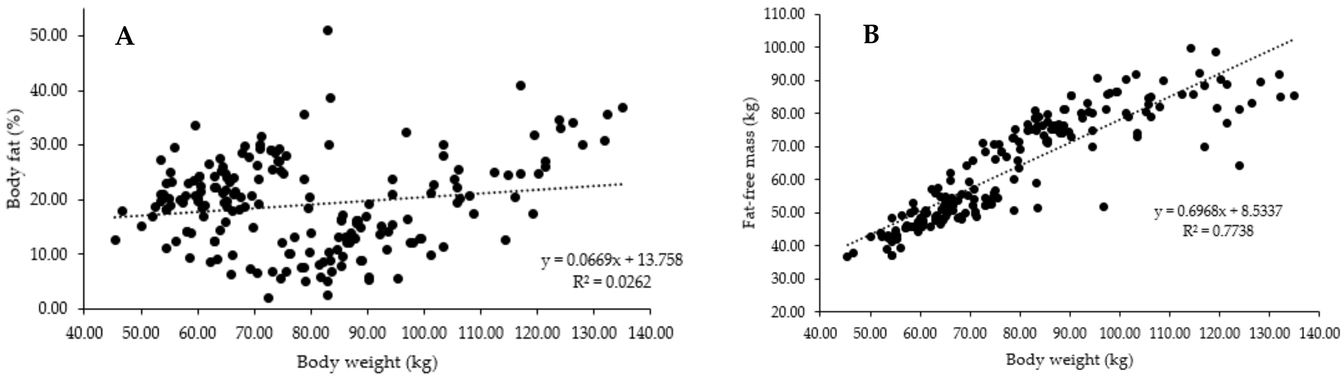

Figure 1. (**A**) Association between body fat percentage and body mass; (**B**) Association between fat-free mass and body mass.

A moderate relationship between RMR/kg of FFM and BF% (r = 0.366; $p < 0.001$) was observed (Figure 2A). Lastly, a strong inverse relationship between RMR/kg and BF% (r = −0.510; $p < 0.001$) was observed (Figure 2B).

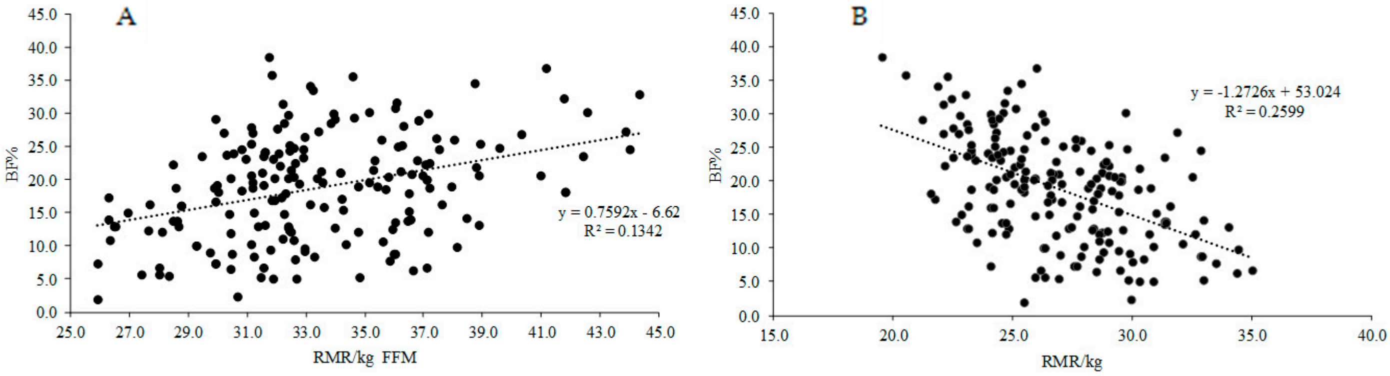

Figure 2. (**A**) Association between body fat percentage and measures of resting metabolic rate per kilogram of fat-free mass; (**B**) Association between body fat percentage and relative resting metabolic rate.

Body mass (β = 0.162), FFM (β = −0.257), RMR/kg (β = −1.017), and RMR/kg of FFM (β = 0.934) were significant predictors of BF%. Table 4 presents a summary of linear regression analysis.

Table 4. Linear regression summary for all athletes.

	Mean ± SD	95% CI	R^2	β	Slope	SEE	*p* Value
Body fat (%)	18.1 ± 8.3	16.8, 19.4					
Weight (kg)	81.5 ± 21.1	78.2, 84.8	0.026	0.162	13.7	8.2	0.026
Fat-free mass (kg)	66.1 ± 16.2	63.5, 68.6	0.066	−0.257	27.6	8.1	<0.001
RMR (kcals/day)	2228 ± 582	2136, 2319	0.004	−0.062	20.9	8.3	0.398
RMR/kg (kcal/kg)	27.5 ± 3.1	26.9, 27.9	0.260	−1.017	53.0	6.8	<0.001
RMR/kg of FFM (kcal/kg)	33.8 ± 4.0	33.2, 34.5	0.134	0.934	−6.6	7.4	<0.001

Data presented as mean ± standard deviation. BMI = body mass index; RMR = resting metabolic rate; kg = kilograms; FFM = fat-free mass; SEE = standard error of the estimate.

5. Discussion

The primary aim of the current study was to examine differences in BF% between athletes grouped by relative RMR. The main findings from the current study indicate that athletes in the high relative RMR group had significantly lower BF% values than those in the low RMR group. Athletes in the high RMR group were also smaller in stature, as seen with a lower body weight and BMI compared to those in the low RMR group. This is the first study to categorize RMR values among athletes and examine differences in BF% across groups of athletes categorized by RMR.

Classifying an athlete's RMR when using absolute values is challenging, as absolute measures of RMR are largely influenced by an athlete's body size [4]. For example, we previously [4] demonstrated that height, body mass, body mass index, fat-free mass, and fat mass were positively associated with absolute measures of RMR in male and female athletes (r = 0.4–0.8) and that body mass was the strongest predictor of RMR, accounting for 78% and 83% of the variation in RMR for male and female athletes, respectively. Moreover, we found that every 1 kg increase in body mass was associated with a 19 kcal and 20 kcal increase in RMR for male and female athletes, respectively [4]. Therefore, expressing RMR relative to body weight, or adjusting for independent factors that influence RMR, is a way to account for differences in body size and allow for more appropriate comparisons between athletes. This may be particularly important when comparing RMR values between men and women. For example, in a study by Arcieroe et al., [18] premenopausal women were found to have a 24% lower RMR compared with younger men (1377 ± 115 vs. 1811 ± 198 kcal/day; $p < 0.01$). However, after adjusting for fat-free mass and weight, only a 4% lower RMR in the premenopausal women was observed when compared with the men (1618 ± 143 vs.

1681 ± 125 kcal/day; $p < 0.01$). We previously reported that male athletes have higher RMR values compared to female athletes (2595 ± 433 vs. 1709 ± 308 kcals; $p < 0.001$). However, after adjusting for differences in body mass ($p = 0.064$) and fat-free mass ($p = 0.084$), the observed differences were no longer significant. Results from the current study found that the average RMR for male athletes was 27.9 kcals/kg when expressed relative to body weight, with 95% of the athletes having an RMR above 22.6 kcals/kg. For female athletes, the average RMR was 25.9 kcals/kg when expressed relative to body weight, with 95% of the athletes having an RMR above 21.9 kcals/kg. These 5th percentiles may therefore represent a low metabolic rate for athletes when expressed relative to body weight. Moreover, relative RMR values at the 95th percentile may represent individuals with a high metabolic rate. More work is needed to evaluate if these relative RMR values may be influenced by hormonal levels, which could explain the wide range in values observed.

Differences in metabolic activity may subsequently influence body fat when accounting for differences in body weight. Relative RMR accounted for 26% of the variance in BF%, indicating that an athlete with a higher metabolic rate would be likelier to have a lower BF%. For both male and female athletes, when expressed relative to body weight, athletes in the highest RMR group had the lowest BF% values compared to the low group, suggesting a higher metabolic activity per kilogram of body weight, potentially contributing to a lower BF%. This finding is contradictory to the theory [5] that low BF% may elicit a metabolic adaptation in athletes leading to suppressed metabolic activity. However, it is possible the BF% values in the current study were not low enough to elicit this metabolic adaptation. Conversely, a higher body weight may indicate a higher BF%, as larger athletes tend to have a higher BF% [19].

It is possible that because athletes in the low RMR group had a higher BF%, it may be a reflection of lower TDEE values over time and an increased likelihood of the athlete having a higher BF%. Further, a higher RMR may lead to challenges for such athletes when attempting to gain body mass (including fat mass) because of the higher metabolic activity, therefore predisposing them to a leaner physique. When RMR was expressed relative to body weight, athletes in the highest RMR group had the lowest BF%. It is worth noting that the observed relationship between RMR and BF% from the current study may represent a bidirectional relationship and therefore limit the ability to identify primary causality (i.e., directionality) within this relationship. The primary aim was to evaluate the influence of RMR on BF%; however, the relationship could be reversed, and BF% may subsequently influence RMR. More work is needed to examine the relationships between RMR and BF% and how intentional manipulation in BF% may influence RMR.

5.1. Limitations

This study is not without limitations. The lack of hormonal data (e.g., luteinizing hormone, thyroid levels, testosterone, catecholamines, etc.) precludes the ability to explain observed differences in BF% and RMR beyond those attributable to differences in body size and FFM. Previous work has suggested that differences in sympathetic nervous system activity, as assessed by noradrenaline kinetics, may partially explain sex differences in RMR. Therefore, the lack of direct measures of hormone values preclude any inference regarding the influence of hormone activity on RMR outcome measures. Similarly, while all athletes included in the study were engaged in regular sport-specific activities, detailed information about current training regimens was not available, which could also influence relationships between RMR and BF%.

5.2. Practical Applications

Practitioners working with athletes with a lower BF% may need to recommend additional energy intake per kilogram of body weight to help with weight gain, if desired. Additionally, these findings can help practitioners better interpret RMR values to classify an athlete with a low, moderate, or high RMR when compared to other athletes and how these values may subsequently influence BF%. It is recommended that future research assess if baseline measures of relative RMR influence training adaptations and weight changes over time.

6. Conclusions

Notable differences in BF% were observed across RMR groups. When expressing RMR relative to body mass, differences in BF% groups were evident for male and female athletes, with those in the high RMR group exhibiting lower BF% values compared to those in the low RMR group. Athletes with a higher relative RMR per kilogram of body mass have a lower BF%, potentially as a result of increased metabolic activity and higher total daily energy expenditure.

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