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The Impact of Total Energy and Carbohydrate Consumption on Power During an Off-Season Training Program in Collegiate Volleyball Players

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ABSTRACT

Adequate energy and carbohydrate intakes are necessary for positive adaptations to exercise training, yet there is limited research examining dietary intake in relation to strength and power in female athletes. The purpose of this study was to determine 1) whether there were significant changes in weekly total energy, carbohydrate, and protein intake; strength; and power; and 2) whether total energy, carbohydrate, and protein intake significantly and positively contributed to changes in strength and power across a controlled eight-week, off-season resistance training program. Eleven collegiate female volleyball players were examined on energy, carbohydrate, and protein intake, strength, and power at two-week intervals using three-day food logs, 3-repetition maximum bench press and back squat, and vertical jump, respectively. Five assessments were conducted on each subject. Alpha level was set at $r < 0.05$. Paired samples t-tests showed improvements in lower body strength and power following eight weeks of training ($r < .05$) despite no significant changes in total energy, carbohydrate, and protein intake. Results of a weighted regression analysis indicated that both total energy and carbohydrate intake influenced lower body power after training ($r < .05$). However, nutrient intake did not impact strength or power at any of the two-week intervals. We believe these findings are related to the neuromuscular adaptations that occur early in training. A longer resistance training program resulting in gains in muscle cross-sectional area (CSA) may be necessary to further examine the contribution of energy, carbohydrate, and protein intake to performance-related variables.

Keywords: energy availability, dietary intake, sports nutrition, female athlete.

INTRODUCTION

Sports performance and training are impacted by energy requirements that vary by the type of sport and duration of each event. Recent research has shown adequate energy and carbohydrate intakes are necessary for positive adaptations to exercise training in athletes (Academy of Nutrition and Dietetics & Dietitians of Canada, 2016; Impey et al., 2020; Kerksick et al., 2018; Slater et al., 2019). Dietary intake has been shown to affect protein synthesis and degradation; thus, optimal energy and carbohydrate intakes play a direct role in the protein accretion necessary for increased muscle fiber hypertrophy and muscular strength adaptations that occur with chronic resistance training (Malowany et al., 2019; Mercer et al., 2020; Slater et al., 2019). By analyzing energy demands of each sport individually, more intelligent decisions can be made to optimize training and identify the specific nutritional needs of athletes.

Loucks et al. (Loucks et al., 2011) recommend using a formula for energy availability (EA) to best estimate the specific energy demands of athletes. An athlete's EA has been defined as the difference between energy intake (EI) and energy expenditure (EE) during training or competition, expressed in kilocalories per kilogram of lean body mass (LBM) per day (Loucks, 2004). Insufficient EA during training results in a loss of muscle mass, suppressed immune function, and slower performance times in endurance athletes (Kerksick et al., 2018; Mountjoy, Sundgot-Borgen, Burke, Carter, Constantini, Lebrun, Meyer, Meyer, et al., 2014). A minimum of 30 kcal/kg of lean body mass (LBM) per day is reported necessary to achieve a normal hormonal milieu with 45 kcal/kg LBM/day being optimal (Loucks et al., 1998).

The American College of Sports Medicine (ACSM), American Dietetic Association (ADA), and Dietitians of Canada (DC) released a joint position statement indicating nutritional needs related to predicted resting metabolic rate (RMR) with a multiplier assigned for average activity participation. Carbohydrate (CHO) intake recommendations ranged from 6-10 grams CHO/kg/d (Academy of Nutrition and Dietetics & Dietitians of Canada, 2016). These recommendations were developed for both men and women engaged in aerobic activities; however, this research was reported to extend to all athletes regardless of the sport or activity performed. In order to better align nutritional recommendations with anaerobic demands, the International Society of Sports Nutrition (ISSN) constructed a different set of nutritional guidelines. For athletes participating in moderate levels of intense training (2-3 hrs/d 5-6 d/wk), recommendations included consumption of 50-80 kcal/kg of bodyweight with 5-8 g CHO/kg/d (Kerksick et al., 2018). A recent review article found that at least 50% of female athletes still did not meet these recommendations for daily total energy intake and CHO consumption (Asencio & Garcia-Galbis, 2015). Unfortunately, this set of guidelines did not provide an objective method of determining exercise intensity and was not developed specifically for females or any individuals participating in specifically defined anaerobic sports. Further, literature confirms a void in nutritional guidelines for women performing anaerobic sports (Areta et al., 2021; Heikura et al., 2022; Holtzman & Ackerman, 2021; Melin et al., 2019; Moore et al., 2022; Wohlgemuth et al., 2021). Appropriate nutrient intake remains a key element for gaining muscle mass, decreasing body fat, improving strength and power, and improving recovery. By monitoring nutrient intake to ensure optimal function, athletes can excel in performance-related measures of strength and power associated with anaerobic sports (Areta et al., 2021; Holtzman & Ackerman, 2021; Logue et al., 2020; Melin et al., 2019; Mountjoy, Sundgot-Borgen, Burke, Carter, Constantini, Lebrun, Meyer, Meyer, et al., 2014; Torres-McGehee et al., 2021; Wohlgemuth et al., 2021).

To date, only one research study has examined the relationship between dietary intake and musculoskeletal strength at baseline and at the conclusion of a controlled, in-season resistance training program in female athletes (Mielgo-Ayuso et al., 2015). Examining elite female volleyball players pre and post training, Mielgo-Ayuso et al. (2015) found that measures of strength and power from baseline to post training significantly increased despite suboptimal daily total energy and CHO consumption. Both absolute maximal strength and power showed a moderate positive relationship with absolute daily total energy intake of players (r = 0.649, p = 0.007 and r = 0.544, p = 0.044 for strength and power, respectively). Maximal strength also demonstrated a moderate positive relationship with absolute daily total CHO intake of players (r = 0.667, p = 0.003). Although the majority of players failed to meet nutritional recommendations using ACSM, ADA, and DC guidelines, significant positive relationships were found between daily total energy intake and strength and power, as well as daily total CHO intake and strength; however, the data were confounded by the fact that it included players who both did and did not meet nutritional recommendations.

The purpose of this study was to determine 1) whether there were significant changes in weekly total energy, carbohydrate, and protein intake; strength; and power; and 2) whether total energy, carbohydrate, and protein intake significantly and positively contributed to changes in strength and power across a controlled eight-week, off-season resistance training program. This knowledge will enable coaches and health professionals to make more informed decisions about the training regimen and progression that would best prepare a female athlete for performance while enhancing her overall health and well-being.

METHODS

Experimental Approach to the Problem

Collegiate, varsity female volleyball players were examined across a controlled 8-week, off-season resistance training cycle. Participants were evaluated for dietary intake, strength, and power across five time points. Dietary intake included weekly total energy, carbohydrate, and protein intake for each participant. Strength was assessed using a 3-repetition maximum (RM) back squat and a 3-RM bench press. Power was assessed using a vertical jump test. Data analyses included 1) changes in dietary intake, strength, and power across a training cycle, 2) changes in strength and power parallel to changes in dietary intake across a training cycle, and 3) periodic changes in strength in power parallel to changes in dietary intake across a training cycle.

Subjects

This study was approved by the University of Miami Institutional Review Board (IRB). Recruitment efforts were made through direct communication and explanation of the research study to the team's head coach and athletes. Prior to data collection, participants were required to sign a consent form and complete a medical history form.

Procedures

Performance parameters assessed included muscular strength (lower and upper body) and muscular power. Muscular strength was measured for the lower and upper body. Participants completed a dynamic warm-up prior to maximal strength testing which began with total body movements and subsequently progressed to include specific muscle group activation. A 3-RM bench press was used to assess upper body strength, while a 3-RM back squat was used to assess lower body strength (McGuigan, 2016; Ritti-Dias et al., 2011). Muscular power was measured for the lower body. A vertical jump test was administered to assess lower body power in participants (Jastrzebski et al., 2014). Prior to testing, a dynamic warm-up was completed to include total body movements and neural activation. A Vertec (Sports Imports, Inc., Columbus, OH, USA) was used to record arm reach and jump height. The difference between the highest flag deflected and the arm reach was used to determine vertical jump height (McGuigan, 2016). A certified strength and conditioning specialist (CSCS) provided supervision and instructions on the dynamic warm-up and all testing protocols.

Dietary intake assessment was performed using a food log was completed on three days of the week according to the protocol recommended by Clark et al. (2003), which included two weekdays and one weekend day, for a 24-hour period as the minimum in an athletic population. Each participant received instructions on how to take photos of all food and beverages consumed within this time-frame using smartphone cameras (Martin et al., 2009). The photos also included text to describe the food and any added dressings, condiments, or toppings. Food logs were analyzed for daily total energy and macronutrient consumption using Nutritionist Pro Version 7.9 software. Daily totals were used to determine weekly mean energy and macronutrient consumption for each participant.

Statistical Analyses

Data was analyzed using SPSS Version 27. Statistical analyses included descriptive statistics, such as means and standard deviations. Paired samples t-tests analyzed differences between baseline and post-testing values of body weight, BMI, LBM, and percent BF. A one-way repeated-measures ANOVA was used to compare the effect of time on dietary intake, strength, and power values across the training program for each participant. Homoscedasticity was evaluated by calculating the ratio of the largest variance to the smallest variance. With a ratio greater than 1.5, the data was classified as heteroscedastic. Due to the heteroscedasticity of the data, a weighted least squares (WLS) regression was used. A WLS regression analysis was used to determine whether changes in dietary intake occurred parallel to changes in strength and power across the training program for each participant. Explanatory variables included energy, carbohydrate, and protein intakes. A priori power analysis conducted in G*Power Version 3.1 on a repeated-measures ANOVA with five measurements, power of 0.80, alpha level of 0.05, and medium effect size (f = 0.25) recommended a sample size of 21 (Faul et al., 2007). Eleven subjects, each with five measurements, produced a sample size of 55 with a power of 0.95. Alpha was set *a priori* at r < .05 for all analyses. The intra-class correlation (ICC) for all dependent variables was R = 0.96.

RESULTS

A total of 11 competitive volleyball players completed an 8-week off-season resistance training program along with submission of 3-day food logs completed every two weeks. None of the women were taking oral contraceptives, and all were eumenorrheic and remained that way throughout the program.

Table 1 provides sample characteristics for ethnicity, resistance training experience, and years of volleyball playing experience. Table 2 shows the physical characteristics measured at baseline and eight weeks later at post-testing. Results from the paired-samples t-test showed significant decreases in BMI ($t(10) = -2.41$, $p = .04$, $d = -1.61$, $CI_{95\%} = -1.260 - -0.090$) and BF ($t(10) = -2.85$, $p = .02$, $d = -1.90$, $CI_{95\%} = -1.327 - -0.137$) along with significant increases in mean values for LBM from 56.68 kg to 58.66 kg at the completion of the program ($t(10) = 3.36$, $p = .01$, $d = 2.24$, $CI_{95\%} = 0.323 - 1.608$).

Energy intake, energy availability (calculated using energy intake), and macronutrient intake variables analyzed from 3-day food logs at baseline and post-testing are presented in Table 3. There were no significant changes in energy intake ($F(2.035, 20.350) = 1.209$, $p = 0.320$, $h^2_p = 0.108$), energy availability, carbohydrate ($F(2.046, 20.459) = 0.940$, $p = 0.409$, $h^2_p = 0.086$) or protein ($F(4, 40) = 0.803$, $p = 0.530$, $h^2_p = 0.074$) following the eight-week training period.

Table 1. Sample Characteristics ($n = 11$)

Variable	***n***	**%**
Race/Ethnicity		
White, non-Hispanic	7	63.64
Hispanic	2	18.18
African-American	1	9.09
Asian	1	9.09
Other	0	0.00
Resistance Training Experience		
<1 year (beginner)	2	18.18
1-2 years (intermediate)	2	18.18
>2 years (advanced)	7	63.64
Volleyball Playing Experience		
<2 years (beginner)	0	0.00
2-4 years (intermediate)	1	9.09
>4 years (advanced)	10	90.91

Data are number (n) and percent (%) in the sample.

Table 2. Physical Characteristics at Baseline and Post-Testing ($n = 11$)

Variable	**Baseline** $\bar{x} \pm$ **SE**	**Post-Testing** $\bar{x} \pm$ **SE**
Age (years)	19.55 ± 0.34	19.55 ± 0.34
Height (m)	1.78 ± 0.04	1.78 ± 0.04
Weight (kg)	71.00 ± 3.76	71.98 ± 3.86*
BMI (kg/m2)	22.38 ± 0.56	21.98 ± 0.56*
Body Fat (%)	19.74 ± 1.48	18.15 ± 1.64*
Lean Body Mass (kg)	56.68 ± 2.45	58.66 ± 2.66**
Upper Body Strength (kg)	39.26 ± 1.15	39.88 ± 1.38
Lower Body Strength (kg)	62.60 ± 3.38	72.31 ± 4.23**
Lower Body Power (W)	4553.22 ± 162.57	4800.93 ± 153.45*

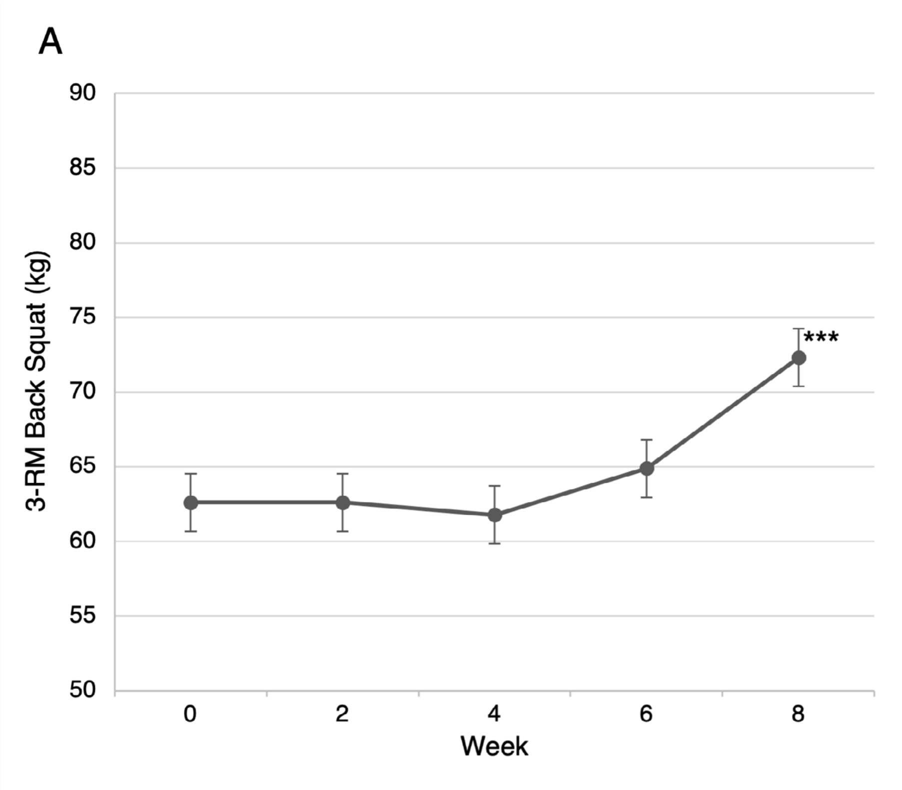
*Data are mean ($\bar{x}$) ± standard error (SE). *Different from pre-test using a paired samples t-test, p < .05. **Different from baseline using a paired samples t-test, p < .01.*

Table 3. Energy, Carbohydrate, and Protein Intake at Baseline and Post-Testing (n = 11)

Variable	Baseline $\bar{x}$ ± SE	Post-Testing $\bar{x}$ ± SE
Energy Intake (Kcal)	1993.78 ± 74.96	2159.25 ± 154.76
Energy Availability (Kcal/kg LBM)	36.16 ± 2.38	38.00 ± 4.43
Carbohydrate (g/kg/day)	3.53 ± 0.41	4.00 ± 0.55
Percent of Total Kcal	47.73%	50.23%
Protein (g/kg/day)	1.35 ± 0.16	1.41 ± 0.14
Percent of Total Kcal	18.58%	18.26%

Data are mean (x) ± standard deviation (SE); analyzed using a paired samples t-test.

Presented in Figure 1 are the results from the one-way repeated-measures ANOVA examining the effect of time on performance-related variables across the off-season. Data for lower body strength violated the assumption of sphericity; therefore, a Greenhouse-Geisser adjustment was applied to that one-way repeated-measures ANOVA. There was a significant effect of time on lower body strength throughout the training program (F(1.740, 17.401) = 21.388, p < 0.001, h^2_p = 0.681, $CI_{95\%}$ = 55.820 - 80.818). Lower body strength at the completion of the study (week eight) was significantly greater than at baseline (M_{diff} = -9.710, SE = 1.988, p = 0.006), week two (M_{diff} = -9.710, SE = 1.708, p = 0.002), week four (M_{diff} = -10.536, SE = 1.509, p < 0.001), and week six (M_{diff} = -7.438, SE = 1.065, p < 0.001). There was also a significant effect of time on lower body power throughout the program (F(4, 40) = 5.332, p = 0.002, h^2_p = 0.348, $CI_{95\%}$ = 52.526 - 63.557). Increases in lower body power were observed between baseline and week two (M_{diff} = -2.886, SE = 0.728, p = 0.027), week six (M_{diff} = -4.849, SE = 1.081, p = 0.012), and week eight (M_{diff} = -3.348, SE = 0.861, p = 0.030). Only week four failed to show any differences from baseline in lower body power (M_{diff} = -2.078, SE = 1.654, p = 1.000). Results for upper body strength are presented in Figure 2, which showed no significant changes from baseline at any time point during the training program (F(4, 40) = 0.496, p = 0.738, h^2_p = 0.047, $CI_{95\%}$ = 36.948 - 42.655).



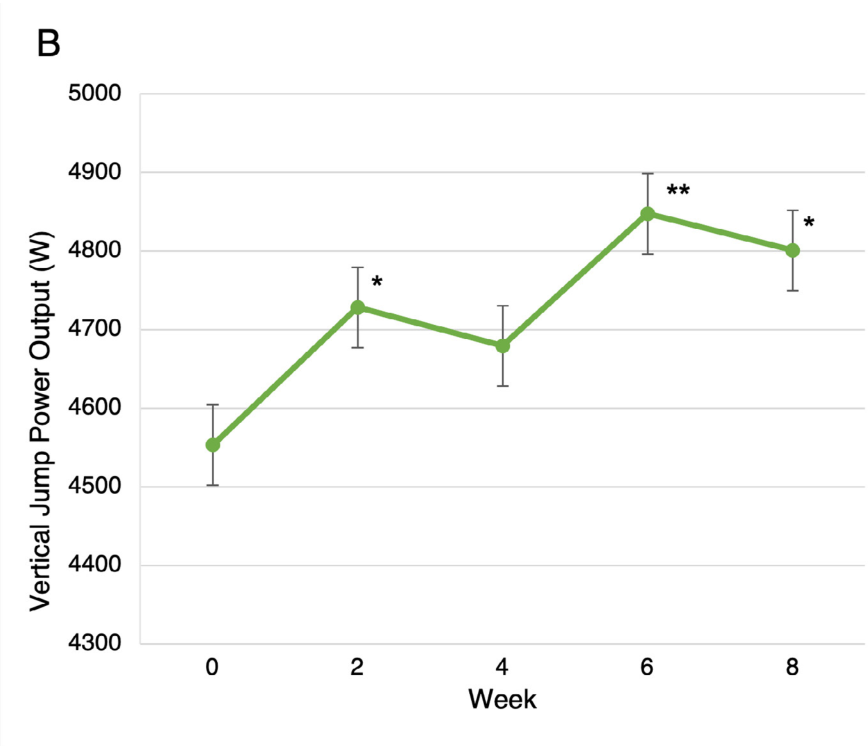


Figure 1. *Lower body strength (A) and power (B) values across the off-season analyzed using repeated-measures ANOVA. *Significantly increased from baseline at the p < .05 level. **Significantly increased from baseline at the p < .01 level. *** Significantly greater than baseline, weeks 2, 4, and 6 at the p < .01 level.*

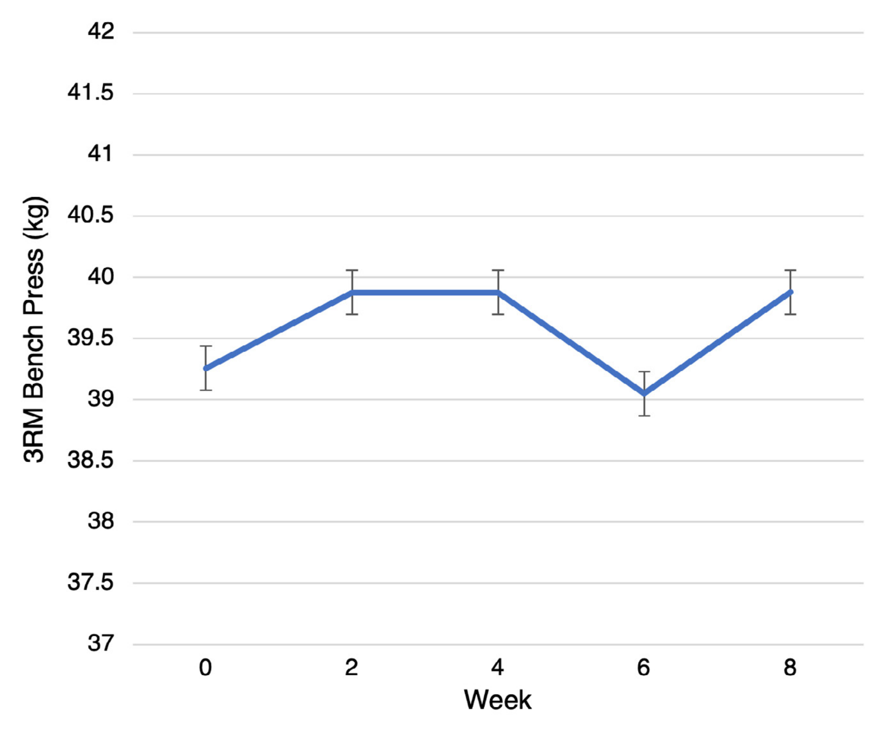


Figure 2. *Upper body strength values across the off-season analyzed using repeated-measures ANOVA.*

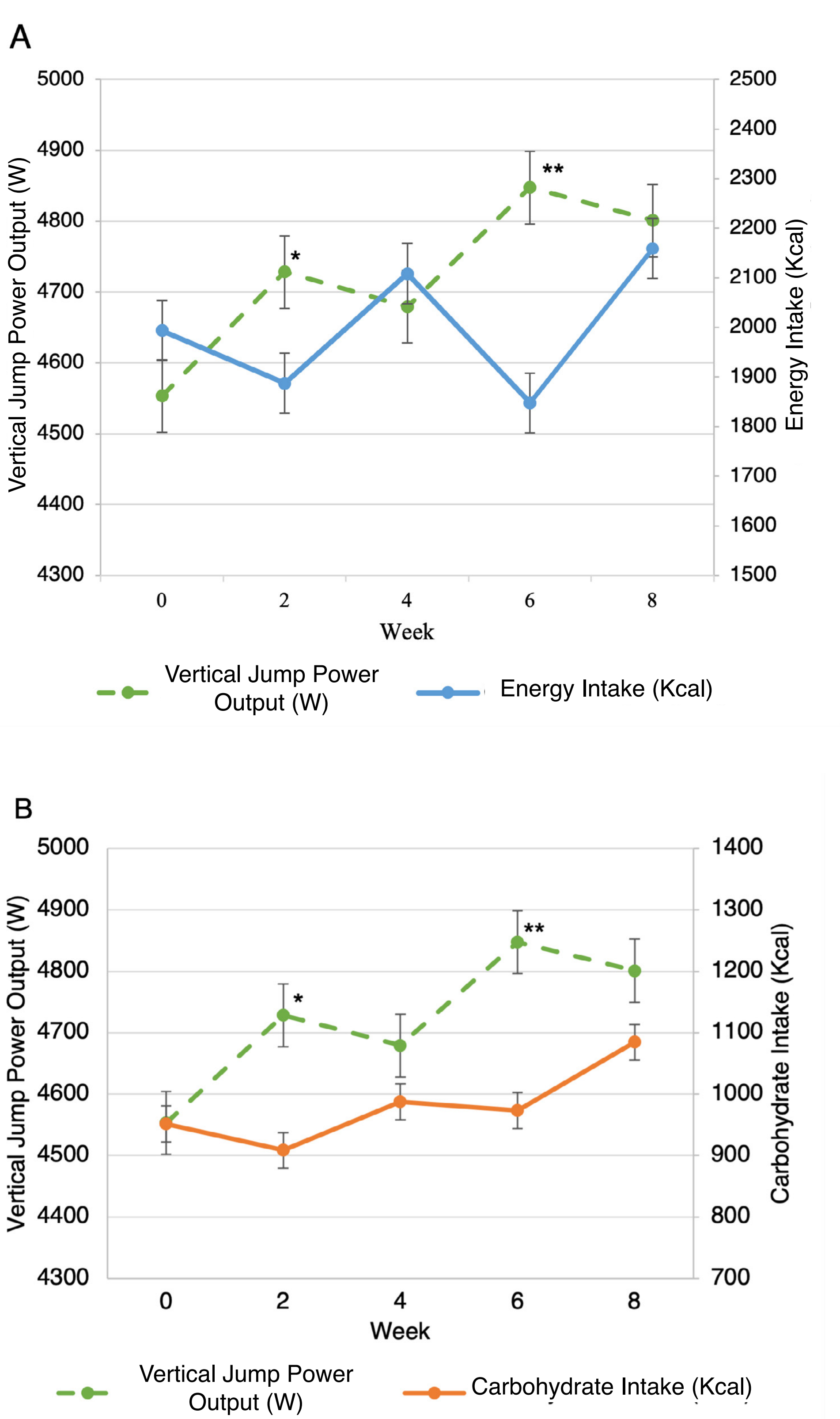


Figure 3. *Changes in lower body power parallel to changes in energy intake (A), and carbohydrate intake (B) analyzed using paired samples t-tests. *Significantly increased from baseline at the p < .01 level. **Significantly increased from week 4 at the p < .05 level.*

WLS were calculated as 1/SE for both lower body strength and power values in order to account for the heteroscedasticity of the data. The weighted regression analysis did not reveal any significant findings between lower body strength and energy intake (b = 0.001, SE = 0.006, t = 0.195, p = 0.850, R^2 = 0.008), carbohydrate (b = 0.049, SE = 0.037, t = 1.347, p = 0.211, R^2 = 0.054), or protein intake (b = 0.370, SE = 1.598, t = 0.232, p = 0.822, R^2 = 0.160) following the training program. The weighted regression analysis was significant and accounted for 51.60% and 43.81% of the variance in lower body power due to energy intake (F(1, 9) = 9.569, p = 0.013) and carbohydrate intake (F(1, 9) = 7.001, p = 0.027), respectively. Results showed that changes in lower body power occurred congruently with changes in energy intake (b = 0.005, SE = 0.002, t = 3.093, p = 0.013, R^2 = 0.481) and carbohydrate intake (b = 0.032, SE = 0.012, t = 2.646, p = 0.027, R^2 = 0.388) across the eight-week training program (Figure 3). Changes in protein intake did not account for any changes in lower body power across the program (b = -0.02, SE = 0.03, t = -0.49, p = 0.64, R^2 = 0.109).

DISCUSSION

Given the fact that many female athletes consume insufficient energy and macronutrients to support their athletic pursuits, this study examined competitive female volleyball players completing performance-related assessments and food logs across an 8-week off-season training season. Volleyball players in our sample evidenced a decrease in BMI and BF of 1.79% and 8.05%, respectively, after training. LBM increased 3.38% following the 8-week resistance training program. These changes occurred despite nonsignificant changes in total energy, carbohydrate and protein intake.

The results of the present study agree with previous literature from Mielgo-Ayuso et al. (2015) who found that volleyball players decreased BF by 4.70% and increased muscle mass by 1.30%. While these changes were not as large as those found in our study, it is important to note that the methods used to assess body composition were different between studies. Body fat was examined using skinfold measurements at eight sites, compared to our study that used hydrodensitometry, which provides a more exacting determination of body composition (Ackland et al., 2012). Mielgo-Ayuso et al. (2015) estimated muscle mass using the Lee prediction equation for skeletal muscle mass (Lee et al., 2000) based on the circumferences of three limbs (arm, mid-thigh, and calf), rather than calculating LBM from hydrodensitometry and BF which was done in the present study. Dietary intake analysis for women in the Mielgo-Ayuso et al. (2015) study showed that some players met the ACSM, ADA, and DC nutritional guidelines while others did not. In our study, all women failed to meet these recommendations. Accompanying improvements in LBM were increases in strength and power. From baseline to post-testing, volleyball players increased lower body strength and power by 13.43% and 5.44%, respectively. This is similar to another study of professional European female volleyball players who improved strength by 10.98% and power by 11.8% after eight weeks of resistance training (González-Ravé et al., 2011). However, González-Rave et al. (2011) evaluated lower body strength using a 2-RM back squat versus a 3-RM test used in the present study. Lower body power of the professional athletes measured using vertical jump height, also doubled after training. This may signify differences in certain physical variables between collegiate and professional level female athletes although gains in strength were comparable between groups.

Upon further analysis, we found that total energy and carbohydrate consumption was associated with increased power output after an eight-week program. Our findings support the study of volleyball players by Mielgo-Ayuso et al. (2015) showing a relationship between absolute measures of macronutrients and performance variables. Our findings may be because total energy and carbohydrates contribute to increasing glycogen stores and energy needed for training and performance thereby positively impacting power output measures. A review by Murray and Rosenbloom (2018) concluded that if adequate glycogen levels are not maintained, exercise intensity and performance decreases. Sufficient availability of glycogen stores is only possible with appropriate energy intake. Previous studies have also shown that if energy and carbohydrate consumption fall to very low levels, female athletes may experience decreased protein synthesis and further declines in performance (Mountjoy et al., 2014). When glycogen stores are depleted, calcium release from the sarcoplasmic reticulum becomes impaired which directly impacts excitation-contraction coupling (Ørtenblad et al., 2011), resulting in slower contraction speed and decreased power output (Hearris et al., 2018).

At the beginning of the study, total energy and carbohydrates were, in turn, 15.06% and 7.27% below recommended established guidelines (Academy of Nutrition and Dietetics & Dietitians of Canada, 2016; Holtzman & Ackerman, 2021; Kerksick et al., 2018; Phillips & van Loon, 2011). Guidelines for recommended energy and carbohydrate intake are equivocal for women in anaerobic sports and there is lack of consistency in how recommended values were derived. Although not significant, energy and carbohydrate intake improved 4.27% and 2.50% respectively, moving closer to recommended levels by the end of the study. This may have accounted for their significant contribution to power output improvement. Interestingly, protein intake was not significantly related to improvements in power output. However, protein intakes were above recommended levels at the start of the program and remained in that position throughout the program. This may explain why protein consumption did not contribute to any performance measures. Interestingly, energy and macronutrients did not contribute to any changes in strength across the eight-week program. This could be due to the relatively short length of training that did not allow sufficient time for increases in myofilamentogenesis to occur that typically accompanies strength training following an initial neural adaptation period. Although our study did show increases in LBM, this may not necessarily provide an exclusive measure of muscle mass as increases in connective tissue, total body water (TBW), and bone mineral content also contribute to LBM (Withers et al., 1998). Accounting for each of those factors independently could have provided more information on protein accretion as a result of training. Nonetheless, changes in these components could explain why increases in LBM may have occurred without commensurate changes in muscle mass in our study.

The lack of a comparison group meeting the recommendations for energy intake and carbohydrate consumption is a limitation of this study. A comparison group performing the same training program while meeting guidelines for macronutrient consumption would enable investigators to examine the contribution of macronutrients to strength and power in women meeting and not meeting current guidelines. The addition of a control group that did not exercise would provide a baseline against which to compare the effects of training. Accuracy of reporting food intake may have been another limitation. Measurement errors may have occurred in the reporting of portion sizes, or participants may have excluded foods due to negative connotations associated with particular foods. These factors may have limited the accuracy of the dietary analysis, ultimately resulting in underestimated energy and carbohydrate intake. Another limitation is the fact that nutrient timing was not assessed. The timing of meals, especially those immediately after and one hour following resistance training, have been shown to increase glycogen repletion, protein synthesis, and recovery rates (Volek, 2004). Examining these details would provide further insight into the contribution of energy and carbohydrate intake on strength and power after training in female athletes. Other variables not controlled for include extraneous physical activity and the amount or quality of sleep, causing corresponding changes in metabolism, altering hunger and satiety levels, and ultimately influencing nutrient intake. Lastly, this study was conducted over an eight-week period. Had this study been extended, and the trend toward increased energy and carbohydrate intake continued, changes in nutrient intake may have been sufficient to increase protein synthesis necessary for muscle hypertrophy. Given the fact that this was only an eight-week resistance training program, it is unlikely that the aggregate energy and carbohydrate consumption would result in muscle hypertrophy.

CONCLUSION

In accordance with our primary outcome, performance-related variables in addition to LBM improved during the off-season program and these improvements occurred congruent with changes in total energy and macronutrient consumption. Upon evaluation of our secondary outcome, we found that periodic changes in total energy and carbohydrate intake examined at two-week intervals did not occur congruently with changes in performance-related variables. It is likely that these intervals may be too brief to examine the influence of nutrient intake on performance measures. In summary, our data indicate training and increased energy and carbohydrate intake improved performance variables in collegiate female volleyball players. However, the nutrition profiles presented by the athletes were still under the recommended guidelines. These results support a more detailed examination of the benefits of energy and carbohydrate consumption on performance-related measures in female collegiate volleyball players during their off-season training.

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ylf001@shsu.edu. The authors have no conflicts of interest to disclose.

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