2019-03-26

The Impact of Total Caloric and Macronutrient Consumption on Strength and Power During an Off-Season Training Program in Collegiate Volleyball Players.

Yvette Figueroa
University of Miami, yvette.figueroa@gmail.com

UNIVERSITY OF MIAMI

THE IMPACT OF TOTAL CALORIC AND MACRONUTRIENT CONSUMPTION ON STRENGTH AND POWER DURING AN OFF-SEASON TRAINING PROGRAM IN COLLEGIATE VOLLEYBALL PLAYERS

By

Yvette L. Figueroa

A DISSERTATION

Submitted to the Faculty
of the University of Miami
in partial fulfillment of the requirements for
the degree of Doctor of Philosophy

Coral Gables, Florida

May 2019

UNIVERSITY OF MIAMI

A dissertation submitted in partial fulfillment of
the requirements for the degree of
Doctor of Philosophy

THE IMPACT OF TOTAL CALORIC AND MACRONUTRIENT CONSUMPTION ON STRENGTH AND POWER DURING AN OFF-SEASON TRAINING PROGRAM IN COLLEGIATE VOLLEYBALL PLAYERS

Yvette L. Figueroa

Approved:

Arlette C. Perry, Ph.D.
Professor of Exercise Physiology

Kevin A. Jacobs, Ph.D.
Associate Professor of Exercise Physiology

Bobby L. Robertson, Ed.D.
Professor of Exercise Physiology

Guillermo Prado, Ph.D.
Dean of the Graduate School

Soyeon Ahn, Ph.D.
Associate Professor of Educational and Psychological Studies

FIGUEROA, YVETTE L. (Ph.D., Exercise Physiology)
The Impact of Total Caloric and Macronutrient Consumption on Strength and Power During an Off-Season Training Program in Collegiate Volleyball Players. (May 2019)

Abstract of a dissertation at the University of Miami.

Dissertation supervised by Professor Arlette C. Perry.
No. of pages in text. (38)

Adequate caloric 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 caloric and macronutrient consumption, strength, and power, and 2) whether total caloric and macronutrient consumption significantly and positively contributed to changes in strength and power across a controlled eight-week, off-season resistance training program. Eleven collegiate-level female volleyball players were examined on macronutrient consumption, 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 for the aforementioned variables. Paired samples t-tests showed improvements in body mass index, lean body mass, percent body fat, and lower body strength and power following eight weeks of training ($p < .05$) despite no significant changes in total calories or macronutrients. Results of a weighted regression analysis indicated that both total caloric consumption and carbohydrate intake influenced lower body power after training ($p < .05$). 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 calories and macronutrients to performance-related variables.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1: Introduction

Extensive research exists examining the physiological demands necessary for optimal performance in sports. Sports performance and training are impacted by energy provisions that vary by the type of sport and duration of each event. Recent research reviews have shown adequate caloric and carbohydrate intakes are necessary for positive adaptations to exercise training in athletes (Burke, Hawley, Wong, & Jeukendrup, 2011; Loucks, Kiens, & Wright, 2011). Dietary intake has been shown to affect protein synthesis and degradation; thus, optimal caloric and carbohydrate intakes positively impact protein accretion necessary for increased muscle fiber hypertrophy and muscular strength adaptations that occur with chronic resistance training (Volek, 2004). 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.

To date, most of the research conducted in athletic populations has focused upon males, specifically males participating in endurance sports. This may be due to the ease of data collection in endurance sports compared to anaerobic sports, the fact that males consistently attain higher absolute values in measures of performance, and/or specific research biases. Research on women in sport has focused upon gender-specific issues, most notably the Female Athlete Triad, which has investigated interrelationships among low energy availability (EA), menstrual irregularities, and low bone mineral density (Manore, Kam, & Loucks, 2007).

To a lesser extent, research has examined the nutritional status of female athletes in relation to energy needs of those participating in aerobic sports including distance running, swimming, and cycling, and aesthetic sports, such as, dance and gymnastics.

Loucks et al. (2011) recommends using a formula for 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). Furthermore, insufficient EA during training results in a loss of muscle mass, suppressed immune function, and slower performance times in endurance athletes (Kreider, Fry, and O'Toole, 1998). A minimum of 30 kcal per kilogram of LBM per day is reported necessary to achieve a normal hormonal milieu with 45 kcal per kilogram of LBM per day being optimal, for achieving a more "balanced EA" (Loucks, Verdun, & Heath, 1998). In a follow-up study of healthy, untrained female volunteers, Loucks and Thuma (2003) examined continuous stationary bicycle ergometry exercise to attain EAs of 10, 20, 30, and 45 kcal per kilogram of LBM per day. Research showed that luteinizing hormone pulsatility was negatively affected at an EA below 30 kcal per kilogram of LBM per day, reducing the metabolic fuels necessary for reproductive and skeletal health, and increasing the likelihood of menstrual cycle dysfunction (Loucks & Thuma, 2003). Therefore, an EA below this threshold provides basic guidelines for minimum total daily caloric requirements for sedentary women beginning an aerobic exercise program (Burke, Loucks, & Broad, 2006).

Current literature confirms a void in nutritional guidelines for women performing anaerobic sports (Burke, Kiens, & Ivy, 2004). Appropriate nutrient intake remains a key element for gaining muscle mass, decreasing body fat, improving strength and power, and/or 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 (Baar & McGee, 2008; Clark, Reed, Crouse, & Armstrong, 2003; Galloway, Lott, & Toulouse, 2014; Maughan, 2002; Sawyer et al., 2013). To better understand the relationship between caloric intake and resistance training, Hartman et al. (2007) examined 56 young men during a 12-week strength training program who added fat-free milk to their diets in comparison to control subjects consuming a beverage of equal caloric and carbohydrate content, but no protein. Both experimental and control groups improved in strength; however, greater increases in muscle fiber size and lean mass were found in the milk group after training (Hartman, Tang, Wilkinson, Tarnopolsky, Lawrence, Fullerton, & Phillips, 2007). Examining a similar group of strength trained women, Josse et al. (2010) found improvements in muscle hypertrophy and lean mass that were significantly greater in the milk than the control group (Josse, Tang, Tarnopolsky, & Phillips, 2010). These studies not only provide evidence of a positive relationship between macronutrient consumption and strength measures, but also indicate that the type of macronutrient consumed may influence resistance training adaptations.

In a recent joint position statement on sports nutrition from the American College of Sports Medicine (ACSM), American Dietetic Association (ADA), and Dietitians of Canada (DC), nutritional needs were based on a calculation using predicted resting metabolic rate (RMR) with a multiplier assigned for average activity participation. RMR was determined through Harris-Benedict predictive equations whereas daily EE was estimated by multiplying the resultant RMR by an activity factor of 1.8 for continuous moderate physical activity for less than 60 min to 2.3 for continuous very heavy physical activity for more than 60 min (Rodriguez, DiMarco, & Langley, 2009). Carbohydrate intake recommendations ranged from 6 to 10 grams of carbohydrate per kilogram of bodyweight per day (Rodriguez, DiMarco, & Langley, 2009). 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. Subsequent research has shown that female athletes in anaerobic sports have failed to attain sufficient nutrient intake using these recommendations which means that these guidelines are either inappropriate for anaerobic female athletes or that these athletes have suboptimal nutrient intake (Asencio & Garcia-Galbis, 2015; Bogdanis, Veligekas, Selima, Christofi, & Pafili, 2013; Cook & Haub, 2007; Currell, 2014; Folasire, Akomolafe, & Sanusi, 2015). Another limitation includes the fact that daily total caloric intakes were estimated based on predictive equations using subjective activity multipliers for continuous aerobic exercise. The recommendations for both daily total caloric and carbohydrate intakes were based upon findings using aerobic exercise. These limitations make it unclear as to whether these guidelines are suitable for women engaged in anaerobic sports.

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, recommendations included consumption of 50-80 kcal per kilogram of bodyweight per day with 5-8 grams of carbohydrate per kilogram of bodyweight per day (Kreider, Wilborn, Taylor, Campbell, Almada, Collins, & Antonio, 2010). The ISSN defined moderate levels of intense exercise as "two to three hours per day of intense exercise performed five to six times per week". Using these guidelines, a recent review article found that at least 50% of female athletes still did not meet recommendations for daily total caloric intake and carbohydrate consumption (Asencio & Garcia-Galbis, 2015). Unfortunately, this set of guidelines did not provide an objective method of determining exercise intensity. Although aforementioned guidelines addressed general anaerobic activities, they were not developed specifically for exercising females or any individuals participating in specifically defined anaerobic sports.

In summary, there are a lack of research studies validating the aforementioned guidelines established for aerobic exercise and extended to all forms of exercise by the ACSM, ADA, and DC joint position statement. Although the ISSN guidelines attempted to address the needs of anaerobic athletes, these guidelines are limited by vague definitions for activity intensity and are not specific to women participating in all types of anaerobic sports. Using either set of guidelines, female anaerobic athletes do not appear to meet recommendations for daily total caloric and carbohydrate intakes.

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, Zourdos, Calleja-González, Urdampilleta, & Ostojic, 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 caloric and carbohydrate consumption. Both absolute maximal strength and power showed a significant, positive relationship with absolute daily total caloric 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 significant, positive relationship with absolute daily total carbohydrate intake of players ($r = 0.667$, $p = 0.003$). Although the majority of players failed to meet nutritional recommendations established for aerobic exercise using ACSM, ADA, and DC guidelines, significant positive relationships were found between daily total caloric intake and strength and power, as well as daily total carbohydrate intake and strength. Unfortunately, the data were confounded by the fact that it included players who both did and did not meet nutritional recommendations.

The investigators reported relationships between absolute caloric and carbohydrate intakes and absolute strength and power before and after training; therefore, periodic changes in the relationships between total caloric and carbohydrate consumption and strength and power were not tracked throughout the season. Large pre/post changes in either direction would have obscured individual relationships observed between nutrient intake and performance variables. Unfortunately, by collecting data before and after the season, investigators were unable to establish whether improvements in strength and power, commonly observed with training, were associated with similar improvements in daily total caloric and carbohydrate intakes. In the present study, caloric and macronutrient (carbohydrate, protein, and fat) consumption and physical variables were evaluated every two weeks so that changes in dietary intake could be examined in relation to changes in physical variables across a training cycle. By examining aforementioned relationships at different time points, results would not be confounded by larger pre/post changes or by examining absolute values only. 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.

The primary purpose of this study was to examine changes in total caloric and macronutrient consumption along with performance measures and to determine whether dietary changes are observed in accordance with changes in performance-related variables across an 8-week training program in collegiate volleyball players. A secondary purpose was to determine whether periodic changes in total caloric and macronutrients occur in accordance with periodic changes in performance-related variables across an off-season training program.

Chapter 2: Methods

Study Design

Competitive female volleyball players from the University of Miami were examined across a controlled 8-week, off-season resistance training cycle. They were evaluated for dietary intake, strength, and power across five time points. Dietary intake included weekly total caloric and macronutrient consumption 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 and Recruitment

Participants for this research study included members of the female, varsity volleyball team at the University of Miami. Recruitment efforts were made through direct communication and explanation of the research study to the team's head coach and athletes. Inclusion criteria for participants included: must be a female, varsity volleyball player at the University of Miami, must be medically cleared for full participation in the sport of volleyball, and must be able to perform exercises in the training program and tests of strength and power without limitations or modifications. Exclusion criteria for participants included: adults unable to consent, individuals who are not yet adults (under age 18), pregnant women, and prisoners. The original sample included 12 participants. However, one participant failed to complete the food logs and was removed from the study; therefore, the final sample included 11 participants. Eight participants in the original sample identified as White, 2 identified as Hispanic/Latino, 1 identified as African-American, and 1 identified as Asian. All participants were required to sign a consent form outlining the risks and benefits associated with this research project, prior to any data collection. Subjects were requested not to change any lifestyle habits such as diet, sleep, and medications, throughout the training program in order to maintain external variables as controlled as possible.

Medical History Form

Each subject completed a medical history form at the same time the informed consent form was signed. Question three, pertaining to changes in lifestyle habits, on the medical history form was asked every two weeks throughout the study. Subjects were also asked to provide information on menstrual cycle status every two weeks throughout the study.

Physical Measures

Underwater Weighing

Underwater weighing is a non-invasive, indirect measure of body density that was used to assess subjects' body composition (LBM vs. fat mass) at baseline and week eight of the study (Buskirk, 1987). Each subject was first weighed on land (InBody570, Cerritos, CA). This value, expressed in kilograms, will represent weight in air. Inside the water tank, the subject was seated in a chair assembly fixed to a hanging scale. The subject maintained her head above water until instructed to forcibly expire as much air as possible. Following maximal expiration, the subject placed her head underwater for three to five seconds to measure weight in water. Body density (BD) was calculated using the formula: BD =Wt[sub.A.]/((Wt[sub.A.] - Wt[sub.w.])/DW) - (RV + GV)]. In this formula, Wt[sub.A.] represents the weight of the subject in air (in kilograms), Wt[sub.w.]

is the weight of the subject in water (in kilograms), DW is the density of the water, RV is the residual volume (in liters), and GV is the gastrointestinal volume (in liters). Water temperature was used to accurately determine water density. RV and GV was estimated at 1.0 L and 100 mL, respectively. Percent body fat (BF) was calculated using the formula: BF = [(4.95/body density - 4.5) x 100] (Francis, 1990; Siri, 1956). Fat mass was calculated by multiplying total body weight by the body fat percentage. LBM was determined by subtracting fat mass from total body weight.

Strength Testing

Participants completed a dynamic warm-up prior to maximal strength testing. The dynamic warm-up began with total body movements and subsequently progressed to include specific muscle group activation. The 3-RM bench press was used to assess upper body (anterior thoracic musculature) strength, while the 3-RM back squat was used to assess lower body (gluteal and posterior femoral musculature) strength (Baechle, & Earle, 2008; Ritti-Dias, Avelar, Salvador, & Cyrino, 2011). Protocols were supervised by a strength and conditioning professional for safe and proper execution of the movements.

For the 3-RM bench press, participants warmed-up by performing two sets of ten repetitions at 50% of the estimated 1-RM, one set of five repetitions using 75% of the estimated 1-RM, and one set of two repetitions using 90% of the estimated 1-RM. A rest of two minutes was given between each warm-up set. The first test attempt was performed at 95% of estimated 3-RM bench press followed by four minutes of passive recovery in accordance with the procedures outlined for strength testing (Baechle, & Earle, 2008; Ritti-Dias, Avelar, Salvador, & Cyrino, 2011). If an athlete failed to complete three repetitions, participants were given four minutes of passive recovery.

Following recovery, the load was decreased by 2.5-5% and another 3-RM attempt was made. If an athlete successfully completed three or more repetitions, participants were given four minutes of passive recovery. Following recovery, the load was increased by 5-10% and another 3-RM attempt was made. This protocol continued for three to five testing sets until participants failed to complete three repetitions of the exercise. The highest load successfully completed for three repetitions was recorded as the participants' 3-RM bench press (Baechle, & Earle, 2008; Ritti-Dias, Avelar, Salvador, & Cyrino, 2011).

For the 3-RM back squat, participants warmed-up by performing two sets of ten repetitions at 50% of the estimated 1-RM, one set of five repetitions using 75% of the estimated 1-RM, and one set of two repetitions using 90% of the estimated 1-RM. A rest of two minutes was given between each of the warm-up sets. The first test attempt was performed at 95% of estimated 3-RM back squat followed by four minutes of passive recovery. If an athlete failed to complete three repetitions, participants were given four minutes of passive recovery. Following recovery, the load was decreased by 5-10% and another 3-RM attempt was made. If an athlete successfully completed three or more repetitions, participants were given four minutes of passive recovery. Following recovery, the load was increased by 10-20% and another 3-RM attempt was made. This protocol continued for three to five testing sets until participants failed to complete three repetitions of the exercise. The highest load successfully completed for three repetitions was recorded as the participants' 3-RM back squat (Baechle, & Earle, 2008; Ritti-Dias, Avelar, Salvador, & Cyrino, 2011).

Power Testing

A vertical jump test was administered to assess lower body (gluteal and posterior femoral musculature) power in participants (Jastrzebski, Wnorowski, Mikolajewski, Jaskulska, & Radziminski, 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. Arm reach was measured with the dominant arm extended overhead in a standing position with feet hip-width apart. After instructions to perform a countermovement prior to the jump, participants jumped as high as possible to deflect the highest flag on the Vertec. Two practice attempts were performed, separated by one minute of passive recovery. Following the practice attempts, maximal attempts were performed. Maximal attempts were separated by one minute of passive recovery. After failing to jump higher for two consecutive attempts, testing was ended. The difference between the highest flag deflected and the arm reach was used to determine vertical jump height (Baechle, & Earle, 2008). A strength and conditioning professional provided supervision and instructions on the dynamic warm-up and testing protocol.

Dietary Intake Assessment

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 timeframe using smartphone cameras (Martin, Kaya, & Gunturk, 2009). The photos also included text to describe the food and any added dressings, condiments, or toppings. Photos of food were taken directly over the plate or table for estimation of portion sizes

(Gemming, Doherty, Kelly, Utter, & Mhurchu, 2013; Williamson et al., 2003). The angle of the smartphone camera was positioned 90 degrees to the plate or table. Photos of beverages were taken at an angle of zero degrees for recording beverage size and product labels. Beverages in opaque containers were required to include a detailed text of contents to accompany the photo. If an opaque container was used, product labels were accompanied with beverages to examine nutritional content.

Food logs were collected at four time points during the training cycle. Using Nutritionist Pro software, food logs were analyzed for daily total caloric and macronutrient consumption. Daily totals were used to determine weekly mean caloric and macronutrient consumption for each participant. Weekly total caloric and macronutrient consumption were analyzed for mean changes across four time points.

Statistical Analyses

Data was analyzed using SPSS Version 22.0 for Windows. 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. A weighted 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. 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, Erdfelder, Lang, & Buchner, 2007). Eleven subjects, each with five measurements, produced a sample size of 55 that provided sufficient power for the within-subjects effect. Alpha was set *a priori* at $p < .05$ for all analyses.

Chapter 3: Results

A total of 12 competitive volleyball players completed an 8-week off-season resistance training program along with submission of 3-day food logs completed every two weeks. Results from medical history forms showed that all women were eumenorrheic and remained that way throughout the program. In addition, none of the women were taking oral contraceptives. One subject failed to complete her food log after week four of the study; therefore, this subject was eliminated as a study participant.

Table 1 provides sample characteristics for ethnicity, resistance training experience, and years of volleyball playing experience. In our final sample, 63.64% (7 players) identified as White, 18.18% (2 players) identified as Hispanic/Latino 9.09%, (1 player) identified as African-American, and 9.09% (1 player) identified as Asian. A total of 90.91% (10 players) had more than four years of volleyball playing experience. Only 9.09% (1 player) had two to four years of volleyball playing experience. A total of 63.64% (7 players) had more than two years of resistance training experience, with only 36.36% (4 players) having two or less years of training experience.

As shown in Table 2, are 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 ($t(10) = -2.41$, $p = .04$) and BF ($t(10) = -2.85$, $p = .02$) following the training program. Paired-samples t-tests also showed significant increases in mean values for LBM from 56.68 kg to 58.66 kg at the completion of the program ($t(10) = 3.36$, $p = .01$).

Calorie consumption, energy availability, and macronutrient intake variables analyzed from 3-day food logs at baseline and post-testing are presented in Table 3. A one-way repeated measures ANOVA was used to compare the effect of time on calorie consumption, energy availability, and macronutrient intake during the training program. There were no significant changes in calorie consumption, energy availability, or macronutrients during the off-season.

As 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 violated the assumption of sphericity; therefore, a Greenhouse-Geisser adjustment was applied to the one-way repeated-measures ANOVA. There was a significant effect of time on lower body strength throughout the training program ($F(4, 40) = 21.39$, $p < .01$). Pairwise comparisons were conducted for post-hoc analysis using Bonferroni's adjustment to examine differences between time points. Lower body strength at the completion of the study (week eight) was significantly greater than at baseline ($M_{\text{diff}} = -9.71$, $SE = 1.99$, $p < .01$), week two ($M_{\text{diff}} = -9.71$, $SE = 1.71$, $p < .01$), week four ($M_{\text{diff}} = -10.54$, $SE = 1.51$, $p < .01$), and week six ($M_{\text{diff}} = -7.44$, $SE = 1.07$, $p < .01$). There was also a significant effect of time on lower body power throughout the program ($F(4, 40) = 5.33$, $p < .01$). Upon further analysis, pairwise comparisons were used in post-hoc testing applied using Bonferroni's adjustment. Increases in lower body power were observed between baseline and week two ($M_{\text{diff}} = -2.89$, $SE = 0.73$, $p = .03$), week six ($M_{\text{diff}} = -4.85$, $SE = 1.08$, $p = .01$), and week eight ($M_{\text{diff}} = -3.35$, $SE = 0.86$, $p = .03$). Only week four failed to show any significant differences from baseline in lower body power ($M_{diff} = -2.08$, $SE = 1.65$, $p = 1.00$). Not presented in figure form are the results for upper body strength, which showed no significant changes from baseline at any time point during the training program.

A weighted regression analysis was used to examine whether changes in dietary intake occurred congruent with changes in strength and power across the training program. Weighted least squares (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 was significant and accounted for 51.5% and 43.8% of the variance in lower body power due to calorie consumption ($F(1, 9) = 9.57$, $p = .01$) and carbohydrate intake ($F(1, 9) = 7.00$, $p = .03$), respectively. Results showed that changes in lower body power occurred congruently with changes in calorie consumption ($b = 0.01$, $SE < 0.01$, $t = 3.09$, $p = .01$) and carbohydrate intake ($b = 0.03$, $SE = 0.01$, $t = 2.65$, $p = .03$) across the 8-week training program. Changes in protein intake did not account for any changes in lower body power across the program ($b = -0.02$, $SE = 0.03$, $t = -0.49$, $p = .64$). The weighted regression analysis did not reveal any significant findings between lower body strength and macronutrient consumption following the training program.

Paired samples t-tests conducted across each 2-week interval were used to compare periodic changes in lower body power with periodic changes in calorie and macronutrient consumption (Figure 2). Results from the paired samples t-test revealed increases in lower body power from baseline to week two ($t(10) = 3.96$, $p < .01$) and from week four to six ($t(10) = 2.47$, $p = .03$). In contrast, no significant changes in calorie consumption or carbohydrate intake occurred during any 2-week cycle in the analysis. Although changes in lower body power were evidenced during two of the four 2-week training cycles, they did not occur in parallel to changes in either calorie consumption or carbohydrate intake across any 2-week interval during the program.

Chapter 4: Discussion

The number of women competing at the collegiate level has tremendously increased in the last few decades (Cheslock, 2007). The National Collegiate Athletic Association (NCAA, 2008) reported that females participating in collegiate athletics increased from 64,390 in 1981-1982 to 172,534 in 2006-2007. Given the fact that many female athletes consume insufficient calories 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. A total of 11 competitive female volleyball completed strength, power, and food logs throughout the program. Our sample included a diverse racial/ethnic group of women similar to that reported by other collegiate volleyball programs (NCAA, 2018). The majority of women had volleyball playing experience and resistance training experience prior to participating in this study. All players were eumenorrheic and remained so throughout the program consuming above the 30 kcal per kilogram of LBM threshold for normal luteinizing hormone pulsatility and cycle status as indicated by Loucks and Thuma (2003).

Volleyball players 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 increases in total calorie and macronutrient consumption. In a study of elite level volleyball players following an 11-week in-season resistance training program, Mielgo-Ayuso, Zourdos, Calleja-González, Urdampilleta, and Ostojic (2015) found 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 hydrodensiometry, 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 what has been shown in 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-Rave et al., 2011). However, González-Rave et al. (2011) evaluated lower body strength using a 2-RM back squat, whereas in our study a 3-RM test was used to determine lower body strength. Vertical jump height is considered an essential parameter in the sport of volleyball (Sheppard et al., 2008); therefore, it was used in both our study and the study by González-Rave et al. (2011) to evaluate lower body power. In that study, players also doubled their increases in lower body power, however, players in the Gonzalez-Rave et al. (2011) study were also professional athletes. This may signify differences in certain physical variables between collegiate and professional level female athletes although gains in strength were comparable between groups.

A number of physiological adaptations occur in response to resistance training that ultimately improve muscular strength and power. Muscular strength is defined as the “maximal force a muscle or muscle group can generate at a specified velocity”; whereas, muscular power is the rate at which that force is produced (Knuttgen & Kraemer, 1987). Initial increases in strength and power are attributed in large part to greater neural drive stemming from activation of the central nervous system. This results in increased alpha-motoneuron activation, motor unit recruitment, and rate coding. Previous studies have also observed increased neurotransmitter release and receptor count along the neuromuscular junction (Deschenes et al., 2000). Following the gains facilitated by the nervous system, further improvements in strength and power stem from structural adaptations that increase muscular cross-sectional area (CSA) (Staron et al., 1994). This growth is achieved via the synthesis and accumulation of contractile elements, specifically myosin and actin, within the myofibrils (Deschenes & Kraemer, 2002).

Upon further analysis, we found that total calorie and carbohydrate consumption significantly contributed to power output in our female athletes after an 8-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 due to the fact that total calories 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 calorie consumption. Previous studies have also shown that if calorie and carbohydrate consumption fall to very low levels, female athletes may experience decreased protein synthesis and further declines in performance (Mountjoy et al., 2014). Glycogen is the primary substrate utilized for ATP production during moderate to high intensity, intermittent exercise (i.e., resistance training). When glycogen stores are depleted, calcium release from the sarcoplasmic reticulum becomes impaired which directly impacts excitation-contraction coupling (Ortenblad, Nielsen, Saltin, & Holmberger, 2011). A consequence of the disruption to excitation-contraction coupling, is slower contraction speed, and thus, decreased power output (Hearris, Hammond, Fell & Morton, 2018).

At the beginning of the study, it should be noted that total calories and carbohydrates were, in turn, 15.06% and 7.27% below recommended established guidelines (Kreider et al., 2010; Philips & Van Loon, 2011; Rodriguez et al., 2009). Guidelines for recommended calorie and carbohydrate intake are equivocal for women in anaerobic sports and there is lack of consistency in how recommended values were derived. Using our values of calorie and carbohydrate consumption both before and after exercise, these macronutrients were below recommended values using any guidelines. Although not significant, calorie 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 as a result of the program. 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, calories and macronutrients did not contribute to any changes in strength across the 8-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 occur without commensurate changes in muscle mass in our study. According to Rankin (2002), significant increases in calorie consumption are required to promote muscle hypertrophy. In the present study, LBM increased in volleyball players without commensurate increases in calorie consumption that was below recommended levels. Increases in non-contractile elements without an increase in calorie consumption may explain why total calories and carbohydrates consumption failed to contribute to improvements in strength. Had this study been extended, and the trend toward increased calorie 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 8-week resistance training program, it is unlikely that the aggregate calorie and carbohydrate consumption would result in muscle hypertrophy.

Our analysis of changes at 2-week intervals failed to show significant contributions of total calories or macronutrients to changes in strength and power during these brief intervals. In fact, when significant increases in power were found from baseline to week 2 and from week 4 to week 6, nonsignificant decreases were found in both calorie and carbohydrate consumption. Therefore, these intervals may have been too brief to evaluate the contribution of calorie and carbohydrate consumption to power. Since increases in lower body power may be due to neuromuscular adaptations, it is not surprising that calories and macronutrients were not related to improvements in performance-related measures during any two-week interval. In the first eight to ten weeks of resistance training, strength and power gains are largely due to increases in neural drive, motor unit recruitment, and firing rates (Duchateau & Enoka, 2002; Staron et al., 1994). These neuromuscular adaptations occur much faster than structural changes needed for the increase in muscle CSA responsible for further increases in strength and power (Folland & Williams, 2007).

Limitations

The lack of a comparison group meeting the recommendations for calorie and carbohydrate consumption is a key limitation of this study. Unfortunately, previous studies of collegiate female volleyball players have not examined nutrient variables in relation to recommended guidelines (Anderson, 2010). Including a comparison group that performed the same off-season 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. It would also provide a more in-depth analysis of the impact nutrients have on physical variables independent of a training program. 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. Participants received instructions on how to measure portion sizes and were required to provide photographs of their foods in addition to the written food logs. However, inconsistent eating schedules and environments, coupled with lack of experience in nutritional recording may have caused these errors. In addition, participants may have excluded foods in the food logs due to negative connotations associated with particular foods. These factors may have limited the accuracy of the dietary analysis, ultimately resulting in underestimated calorie consumption 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 calorie and carbohydrate intake on strength and power after training in female athletes.

Other variables not controlled for include physical activity unrelated to volleyball or physical training and the amount or quality of sleep. Extraneous physical activity would have increased energy expenditure, causing a corresponding increase in metabolism, altering hunger and satiety levels, and ultimately influencing nutrient intake. These extraneous variables may have influenced our findings. Sample size was low;

however, the use of repeated-measures statistical analysis increased the power of this study.

Chapter 5: Conclusion

Our study showed that collegiate-level volleyball players representative of other institutions showed improvements in LBM, strength, and power across an 8-week off-season training program. This occurred despite no significant increases in total calorie or macronutrient consumption and despite the fact that total calories and carbohydrates were below recommended levels. Despite lower than recommended daily intakes, both total calorie and carbohydrate consumption increased in parallel to increases in power output in competitive volleyball players during the off-season training season. Therefore, 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 calorie and macronutrient consumption. Upon evaluation of our secondary outcome, we found that periodic changes in total caloric and carbohydrate intake examined at 2-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 study supports a more detailed examination of the benefits of calorie and carbohydrate consumption on performance-related measures in female collegiate volleyball players during their off-season training.

Recommendations for the Future

It is suggested that future studies examine a control group of non-athletes, a second training group of trained volleyball players meeting recommended guidelines, and a third group of trained volleyball players not meeting recommended guidelines to compare the contribution of total calories and macronutrients to strength and power in one study. We feel it is necessary to examine extended periodic changes in dietary variables to performance-related measures in a longer resistance training program of competitive female volleyball players.

References

Ackland, T. R., Lohman, T. G., Sundgot-Borgen, J., Maughan, R. J., Meyer, N. L Stewart, A. D., & Müller, W. (2012). Current status of body composition assessment in sport. *Sports Medicine, 42*(3), 227-249. doi:10.2165/11597140-000000000-00000

Anderson, D. E. (2010). The impact of feedback on dietary intake and body composition of college women volleyball players over a competitive season. *Journal of Strength and Conditioning Research, 24*(8), 2220–2226. doi:10.1519/jsc.0b013e3181def6b9

Asencio, L. B., & Garcia-Galbis, M. R. (2015). Energy and macronutrient intake in female athletes. *Nutrición Hospitalaria*, *32*(5), 1936–1948. doi:10.3305/nh.2015.32.5.9280

Baar, K., & McGee, S. (2008). Optimizing training adaptations by manipulating glycogen. *European Journal of Sport Science*, *8*(2), 97–106. doi:10.1080/17461390801919094

Baechle, T. R., & Earle, R. W. (2008). Essentials of strength training and conditioning - 3rd edition (3rd ed.). Champaign, IL: Human Kinetics Publishers.

Baker, L. B., Heaton, L. E., Nuccio, R. P., & Stein, K. W. (2014). Dietitian-observed macronutrient intakes of young skill and team-sport athletes: adequacy of pre, during, and postexercise nutrition. *International Journal of Sport Nutrition and Exercise Metabolism*, *24*(2), 166–176. doi:10.1123/ijsnem.2013-0132

Bogdanis, G. C., Veligekas, P., Selima, E., Christofi, E., & Pafili, Z. (2013). Elite high jumpers exhibit inadequate nutrient intakes. *Journal of Physical Education and Sport*, *13*(3), 330–337. doi:10.7752/jpes.2013.03054

Burke, L. M., Cox, G. R., Cummings, N. K., & Desbrow, B. (2001). Guidelines for daily carbohydrate intake. *Journal of Sports Medicine*, *31*(4), 267–299.

Burke, L. M., Hawley, J. A., Wong, S. H. S., & Jeukendrup, A. E. (2011). Carbohydrates for training and competition. *Journal of Sports Sciences*, *29*(sup1), S17–S27. doi:10.1080/02640414.2011.585473

Burke, L. M., Loucks, A. B., & Broad, N. (2006). Energy and carbohydrate for training and recovery. *Journal of Sports Sciences*, *24*(7), 675–685. doi:10.1080/02640410500482602

Buskirk, E.R. The 1986 CH McCloy Research Lecture. Body composition analysis: the past, present and future. *Research Quarterly for Exercise and Sport. 1987; 58*:1-10.

Cheslock, J. (2007). Who's playing college sports? Trends in participation. *Sport, Power, and Society,* 143-157. doi:10.4324/9780429497216-14

Clark, M., Reed, D., Crouse, S., & Armstrong, R. (2003). Pre- and post-season dietary intake, body composition, and performance indices of NCAA division I female soccer players. *International Journal of Sport Nutrition and Exercise Metabolism*, *3*(13).

Deschenes, M. R., Judelson, D. A., Kraemer, W. J., Meskaitis, V. J., Volek, J. S., Nindl, B. C., Deaver, D. R. (2000). Effects of resistance training on neuromuscular junction morphology. *Muscle & Nerve, 23*(10), 1576-1581. doi:10.1002/1097-4598(200010)23:103.3.co;2-a

Deschenes, M. R., & Kraemer, W. J. (2002). Performance and physiologic adaptations to resistance training. *American Journal of Physical Medicine & Rehabilitation, 81*(Supplement). doi:10.1097/00002060-200211001-00003

Duchateau, J., & Enoka, R. M. (2002). Neural adaptations with chronic activity patterns in able-bodied humans. *American Journal of Physical Medicine & Rehabilitation, 81*(Supplement). doi:10.1097/00002060-200211001-00004

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*, 175-191.

Ferreira, L.C., Schilling, B.K., Weiss, L.W., Fry, A.C., & Chiu, L.Z. (2010). Reach height and jump displacement: implications for standardization of reach determination. *Journal of Strength and Conditioning Research, 24*(6), 1596-1601. doi:10.1519/JSC.0b013e3181d54a25

Folasire, O. F., Akomolafe, A. A., & Sanusi, R. A. (2015). Does nutrition knowledge and practice of athletes translate to enhanced athletic performance? Cross-sectional study amongst Nigerian undergraduate athletes. *Global Journal of Health Science*, *7*(5), 215–225. doi:10.5539/gjhs.v7n5p215

Folland, J. P., & Williams, A. G. (2007). The adaptations to strength training. *Sports Medicine, 37*(2), 145-168. doi:10.2165/00007256-200737020-00004

Francis, Kennon T. (1990). Body-composition assessment using underwater weighing techniques. *Physical Therapy, 70*(10), 657.

Galloway, S. D. R., Lott, M. J. E., & Toulouse, L. C. (2014). Preexercise carbohydrate feeding and high-intensity exercise capacity: Effects of timing of intake and carbohydrate concentration. *International Journal of Sport Nutrition and Exercise Metabolism*, *24*(3), 258–266. doi:10.1123/ijsnem.2013-0119

Gemming, L., Doherty, A., Kelly, P., Utter, J., & Mhurchu, C. N. (2013). Feasibility of a SenseCam-assisted 24-h recall to reduce under-reporting of energy intake. *European Journal of Clinical Nutrition*, *67*, 1095–1099.

González-Ravé, J. M., Arija, A., & Clemente-Suarez, V. (2011). Seasonal changes in jump performance and body composition in women volleyball players. *Journal of Strength and Conditioning Research, 25*(6), 1492-1501. doi:10.1519/jsc.0b013e3181da77f6

Hartman, Joseph W., Tang, Jason E., Wilkinson, Sarah B., Tarnopolsky, Mark A., Lawrence, Randa L., Fullerton, Amy V., & Phillips, Stuart M. (2007). Consumption of fat-free fluid milk after resistance exercise promotes greater lean mass accretion than does consumption of soy or carbohydrate in young, novice, male weightlifters. *American Journal of Clinical Nutrition AJN, 86*(2), 373-381.

Hearris, M., Hammond, K., Fell, J., & Morton, J. (2018). Regulation of muscle glycogen metabolism during exercise: implications for endurance performance and training adaptations. *Nutrients, 10*(3), 298. doi:10.3390/nu10030298

InBody570 [Body composition analyzer]. (n.d.). Cerritos, CA: Biospace, Inc.

Jastrzebski, Z., Wnorowski, K., Mikolajewski, R., Jaskulska, E., & Radziminski, L. (2014). The effect of a 6-week plyometric training on explosive power in volleyball players. *Baltic Journal of Health and Physical Activity, 6*(2). doi:10.2478/bjha-2014-0008

Josse, A., Tang, J., Tarnopolsky, M., & Phillips, S. (2010). Body composition and strength changes in women with milk and resistance exercise. *Medicine and Science in Sports and Exercise, 42*(6), 1122-30.

Knuttgen, H. G., & Kraemer, W. J. (1987). Terminology and measurement in exercise performance. *Journal of Strength and Conditioning Research, 1*(1), 1-10. doi:10.1519/00124278-198702000-00001

Kreider, R., O'Toole, M., Fry, A., Kibler, W., Nieman, D., Whelan, J., & Lehmann, M. (1998). Overtraining in sport. *Medicine & Science in Sports & Exercise, 30*(Supplement), 225.

Kreider, R., Wilborn, C., Taylor, L., Campbell, B., Almada, A., Collins, R., Antonio, J. (2010). ISSN exercise & sport nutrition review: research & recommendations. *Journal of the International Society of Sports Nutrition, 7*, 7.

Lee, R. C., Wang, Z., Heo, M., Ross, R., Janssen, I., & Heymsfield, S. B. (2000). Total-body skeletal muscle mass: development and cross-validation of anthropometric prediction models. *The American Journal of Clinical Nutrition, 72*(3), 796-803. doi:10.1093/ajcn/72.3.796

Loucks, A. B., Kiens, B., & Wright, H. H. (2011). Energy availability in athletes. *Journal of Sports Science*, *29*(S1), S7–S15.

Loucks, A. B., & Thuma, J. R. (2003). Luteinizing hormone pulsatility is disrupted at a threshold of energy availability in regularly menstruating women. *The Journal of Clinical Endocrinology & Metabolism, 88*(1), 297-311.

Manore, M. M., Kam, L. C., & Loucks, A. B. (2007). The female athlete triad: components, nutrition issues, and health consequences. *Journal of Sports Sciences*, *25*(sup1), S61–S71. doi:10.1080/02640410701607320

Martin, C. K., Kaya, S., & Gunturk, B. K. (2009). Quantification of food intake using food image analysis. 2009 Annual International Conference of the IEEE Engineering in Medicine and Biology Society. doi:10.1109/iembs.2009.5333123

Mielgo-Ayuso, J., Zourdos, M. C., Calleja-González, J., Urdampilleta, A., & Ostojic, S. M. (2015). Dietary intake habits and controlled training on body composition and strength in elite female volleyball players during the season. *Applied Physiology, Nutrition, and Metabolism*, *40*(8), 827–834. doi:10.1139/apnm-2015-0100

Mountjoy, M., Sundgot-Borgen, J., Burke, L., Carter, S., Constantini, N., Lebrun, C., Ljungqvist, A. (2014). The IOC consensus statement: beyond the female athlete triad—relative energy deficiency in sport (RED-S). *British Journal of Sports Medicine, 48*(7), 491-497. doi:10.1136/bjsports-2014-093502

Murray, B., & Rosenbloom, C. (2018). Fundamentals of glycogen metabolism for coaches and athletes. *Nutrition Reviews, 76*(4), 243-259. doi:10.1093/nutrit/nuy001

National Collegiate Athletic Association (NCAA). (2008). *NCAA sports sponsorship and participation rates report 1981-82–2006-07.* Indianapolis, IL: NCAA.

NCAA. (2018). *NCAA Demographics Database* [Data visualization dashboard]. Retrieved from http://www.ncaa.org/about/resources/research/ncaa-demographics-database.

Ørtenblad, N., Nielsen, J., Saltin, B., & Holmberg, H. (2011). Role of glycogen availability in sarcoplasmic reticulum Ca^{+2} kinetics in human skeletal muscle. *The Journal of Physiology, 589*(3), 711-725. doi:10.1113/jphysiol.2010.195982

Rankin, J. W. (2002). Weight loss and gain in athletes. *Current Sports Medicine Reports, 1*(4), 208-213. doi:10.1249/00149619-200208000-00004

Rasmussen, C. J. (2012). *Nutritional guidelines for athletic performance: the training table*. (L. W. Taylor, Ed.) (pp. 117–137). United States: CRC Press.

Rezaeimanesh, D., & Farsani, P. A. (2011). The effect of a 6-week isotonic training period on lower body muscle EMG changes in volleyball players. *Procedia - Social and Behavioral Sciences*, *30*, 2129–2133. doi:10.1016/j.sbspro.2011.10.413

Ritti-Dias, R. M., Avelar, A., Salvador, E. P., & Cyrino, E. S. (2011). Influence of previous experience on resistance training on reliability of one-repetition maximum test. *Journal of Strength and Conditioning Research*, *25*(5), 1418–1422. doi:10.1519/jsc.0b013e3181d67c4b

Rodriguez, N. R., DiMarco, N. M., & Langley, S. (2009). Nutrition and athletic performance. *Medicine & Science in Sports & Exercise*, 709–731. doi:10.1249/MSS.0b013e318190eb86

Sawyer, J. C., Wood, R. J., Davidson, P. W., Collins, S. M., Matthews, T. D., Gregory, S. M., & Paolone, V. J. (2013). Effects of a short-term carbohydrate-restricted diet on strength and power performance. *Journal of Strength and Conditioning Research*, *27*(8), 2255–2262. doi:10.1519/jsc.0b013e31827da314

Sheppard, J. M. (2009). Twelve-month training-induced changes in elite international volleyball players. *Journal of Strength and Conditioning Research, 23*(7), 2096–2101.

Sheppard, J. M., Cronin, J. B., Gabbett, T. J., Mcguigan, M. R., Etxebarria, N., & Newton, R. U. (2008). Relative importance of strength, power, and anthropometric measures to jump performance of elite volleyball players. *Journal of Strength and Conditioning Research, 22*(3), 758-765. doi:10.1519/jsc.0b013e31816a8440

Siri, W. The gross body composition of the body. In: Tobias C, Lawrence J, eds. Advances in Biological and Medical Physics IV. New York, NY: Academic Press Inc; 1956; 239-280.

Staron, R. S., Karapondo, D. L., Kraemer, W. J., Fry, A. C., Gordon, S. E., Falkel, J. E., Hikida, R. S. (1994). Skeletal muscle adaptations during early phase of heavy-resistance training in men and women. *Journal of Applied Physiology, 76*(3), 1247-1255. doi:10.1152/jappl.1994.76.3.1247

Tilgner, S.A., & Schiller, M.R. (1989). Dietary intakes of female college athletes: the need for nutrition education. *Journal of the American Dietetic Association, 89*(7), 967-969.

Volek, J. S. (2004). Influence of nutrition on responses to resistance training. *Medicine & Science in Sports & Exercise*, *36*(4), 689–696. doi:10.1249/01.mss.0000121944.19275.c4

Volek, J. S., Forsythe, C. E., & Kraemer, W. J. (2006). Nutritional aspects of women strength athletes. *British Journal of Sports Medicine*, *40*(9), 742–748. doi:10.1136/bjsm.2004.016709

Wenzel, R. K., Valliant, M. W., Garner, B. H., & Garner, J. C. (2011). Inadequacies of macronutrient intake of intercollegiate female athletes. *Journal of the American Dietetic Association, 111*(9), A98. doi:10.1016/j.jada.2011.06.365

Williamson, D. A., Allen, H. R., Martin, P. D., Alfonso, A. J., Gerald, B., & Hunt, A. (2003). Comparison of digital photography to weighed and visual estimation of portion sizes. *Journal of the American Dietetic Association*, *103*(9), 1139–1145. doi:10.1016/s0002-8223(03)00974-x

Withers, R. T., Laforgia, J., Pillans, R. K., Shipp, N. J., Chatterton, B. E., Schultz, C. G., & Leaney, F. (1998). Comparisons of two-, three-, and four-compartment models of body composition analysis in men and women. *Journal of Applied Physiology, 85*(1), 238-245. doi:10.1152/jappl.1998.85.1.238

Figures

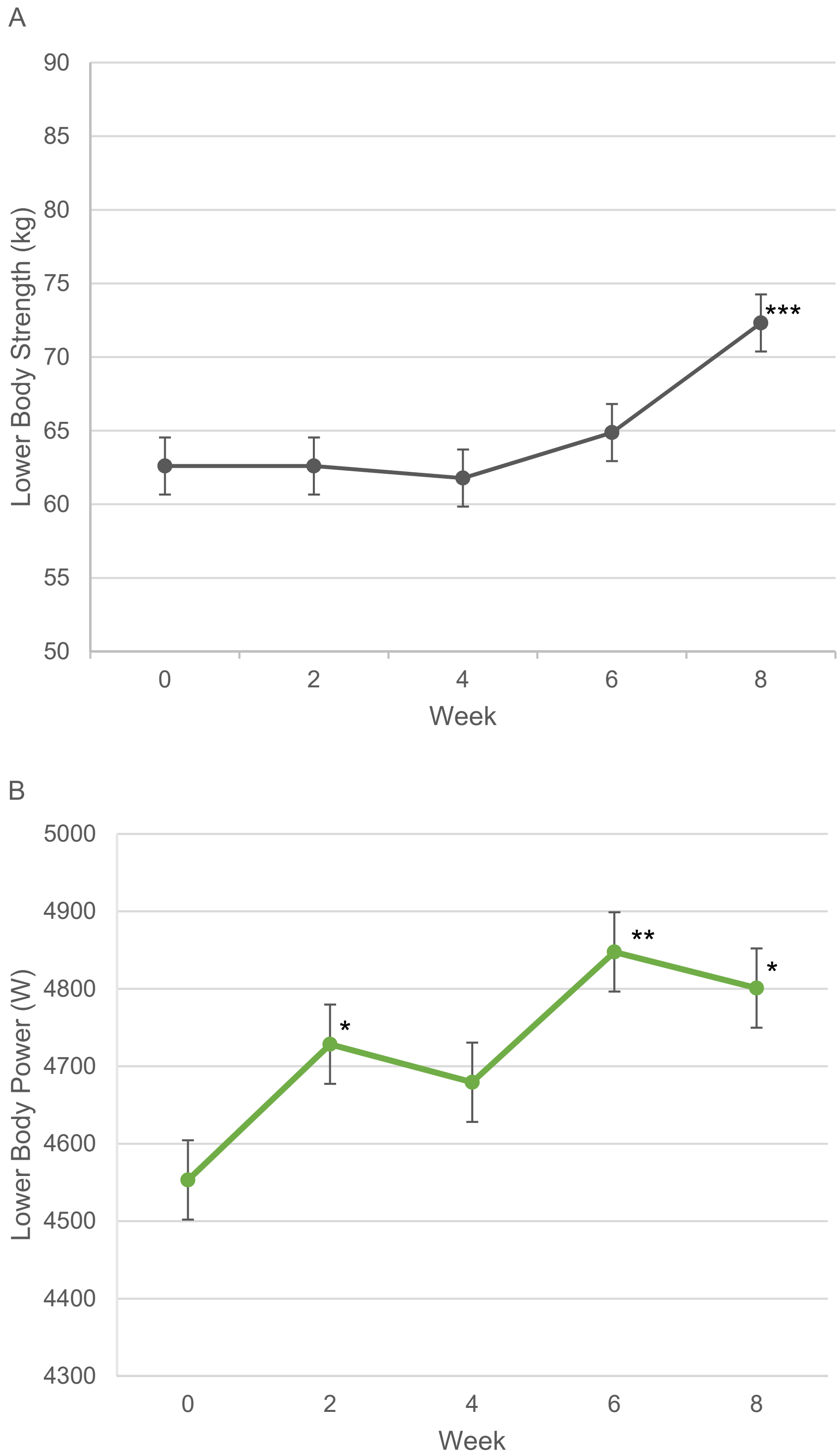

Figure 1. Lower body strength (A) and power (B) values across the off-season analyzed using repeated-measures ANOVA. *Significantly increased from baseline at the $p < .05$ level. **Significantly increased from baseline at the $p < .01$ level. *** Significantly greater than baseline, weeks 2, 4, and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

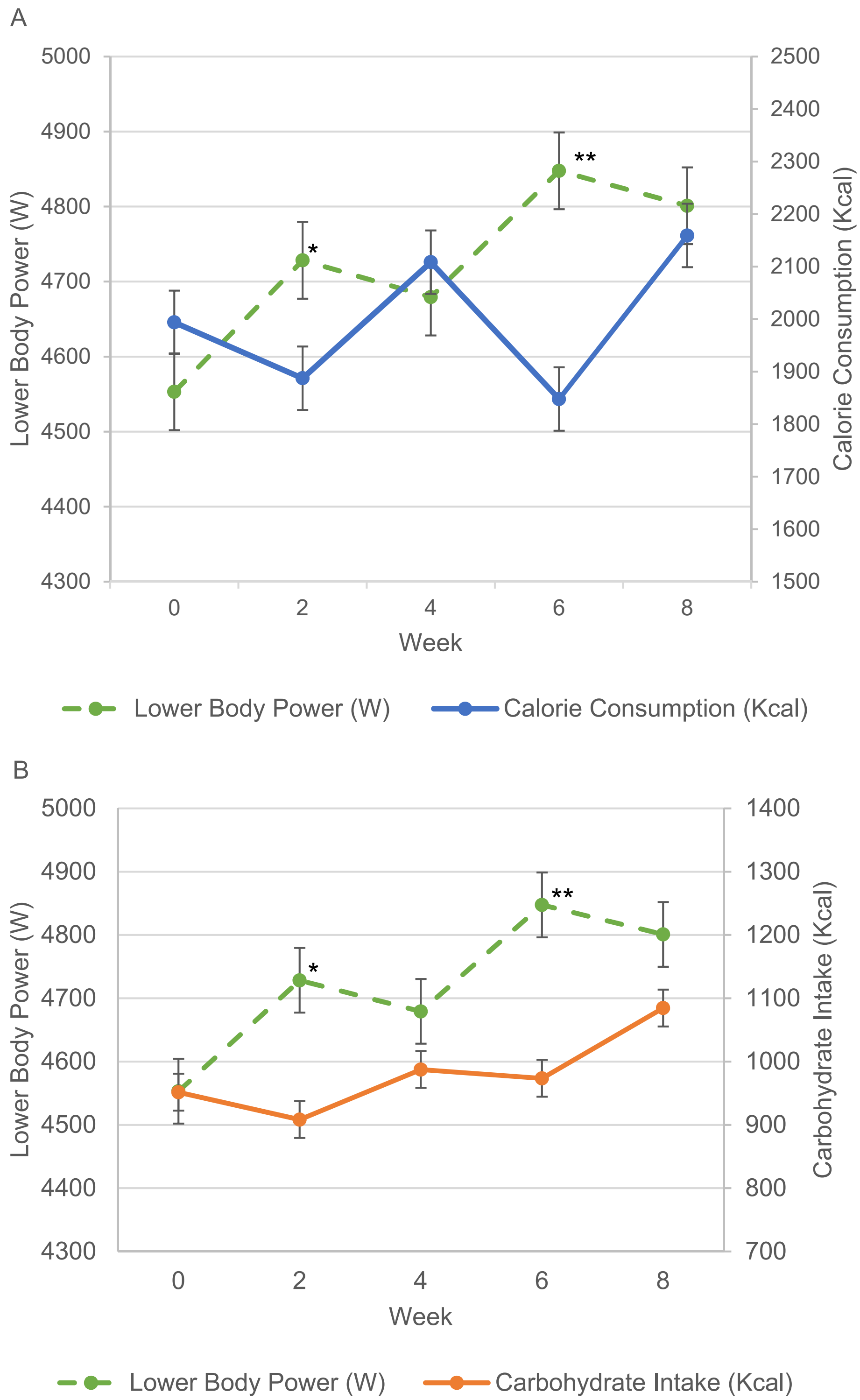

Figure 2. *Changes in lower body power parallel to changes in calorie consumption (A), and carbohydrate intake (B) analyzed using paired samples t-tests. *Significantly increased from baseline at the p < .01 level. **Significantly increased from week 4 at the p < .05 level.*

Tables

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 $\bar{x}$ ± SE	Post-Testing $\bar{x}$ ± 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/m^2)	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. *Calorie Consumption and Macronutrient Intake at Baseline and Post-Testing (n = 11)*

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

Data are mean ($\overline{x}$) ± standard deviation (SE); analyzed using a paired samples *t*-test.