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HIGH DIETARY COGNITIVE RESTRAINT, INDEPENDENT OF DISINHIBITION, IS ASSOCIATED WITH LOWER ENERGY AVAILABILITY IN EXERCISING WOMEN

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ABSTRACT

Subclinical disordered eating behavior, as indicated by a high dietary cognitive restraint (CR), is highly prevalent in premenopausal exercising women with chronic energy deficiency and acts as a key factor in promoting the development of the Female Athlete Triad. Disinhibition is a counter-regulatory response to the restriction of food intake and represents an absence or reversal of inhibition. The effect that disinhibition has on energetic characteristics alongside CR has yet to be examined in exercising women. The purpose of this study is to compare energetic characteristics in exercising women when categorized by CR and disinhibition status. We hypothesized that : (1) The High CR + Normal Disinhibition group would have a lower energy intake and EA compared to the High CR + High Disinhibition group; (2) The High CR + Normal Disinhibition group would have lower resting energy expenditure REE, corroborated by lower TT3 and higher ghrelin, compared to the High CR and High Disinhibition group. This was a cross-sectional study that included data in 85 women who were 23±4 years old, weighed 57.6±5.9 kg, had a VO_2 max of 47±7mL/kg/min, and had a percent body fat of 25±5. Subjects were retrospectively characterized by cognitive restraint and disinhibition scores into three groups: (1) High CR + High Disinhibition (n=14), (2) High CR + Normal Disinhibition (n=27), and (3) Normal CR + Normal Disinhibition (n=44). CR and disinhibition scores were obtained from the Three Factor Eating Questionnaire. We operationally defined a high CR score as ≥11; whereas a normal CR score was <11. We operationally defined a high disinhibition score as ≥8; whereas a normal disinhibition score was <8. Body composition was measured using dual energy x-ray absorptiometry. Energy intake (EI) was determined using 3 day diet logs. Energy availability (EA) was defined as (EI - purposeful exercise calories (EEE))/kg lean body mass (LBM) and calculated for a 7 day period. Resting energy expenditure (REE) was measured using a ventilated hood system and we computed the ratio of the actual REE/predicted REE (REE/pREE) with predicted REE derived from the Harris Benedict equation. Fasting blood samples were obtained twice during the study period and were pooled and assayed for triiodothyronine (T_3) and ghrelin concentrations. EA was significantly lower in the High CR + Normal Disinhibition group compared to the Normal CR + Normal Disinhibition group (34.6 kcal/kg LBM vs. 43.5 kcal/kg LBM, $p=0.005$). Whereas, there were no significant differences in EA ($p>0.05$) between the High CR + High Disinhibition group and the other groups. Measures of EI revealed no significant differences ($p=0.705$) between women with High CR + Normal Disinhibition and those with High CR + High Disinhibition. However, women with Normal CR + Normal Disinhibition consumed significantly higher EI compared to High CR + Normal Disinhibition and High CR + High Disinhibition (2003 kcal/d vs. 1740 kcal/d and. 1677 kcal/d, $p<0.05$). There were no significant differences ($p>0.05$) between groups for EEE and lean body mass. Our findings demonstrated no significant differences ($p>0.05$) in REE, REE/pREE, T_3 and ghrelin concentrations between groups. CR score was negatively correlated with EA ($r=-0.351$, $p=0.001$), EI ($r=-0.379$, $p<0.001$) and REE/pREE ($r=-0.255$, $p=0.018$). Disinhibition score was not significantly associated ($p>0.05$) with any of the EA parameters. However, disinhibition score was positively correlated with body mass ($r=0.283$, $p=0.008$) and negatively correlated with total exercise volume ($r=-0.248$, $p=0.027$). When discriminating solely by CR score, both EA and EI were significantly lower in exercising women with high CR (35.4 kcal/kg LBM and 1719 kcal/d, respectively) vs. women with normal CR (43.7 kcal/kg and 2031 kcal/d, respectively). These findings suggest an association between CR score and EA, primarily via EI, in exercising women. Women with a high CR and normal disinhibition have a lower EA compared to those with normal CR and disinhibition. However, our findings demonstrate that disinhibition score does not further discriminate these women in terms of EA and EI. Thus, the CR subscale alone may be a better psychometric indicator of EA in exercising women than the combination of CR and disinhibition.

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Chapter 1

Literature Review

The Female Athlete Triad

The Female Athlete Triad is the association between energy availability, menstrual function, and bone mineral density, which have clinical manifestations including low energy availability with or without disordered eating, functional hypothalamic amenorrhea, and osteoporosis (Nattiv et al., 2007). Each of the Triad components lie along a continuum ranging from optimal to severely pathological, and when these are consolidated into one illustration, the result is a model as seen in Figure 1.

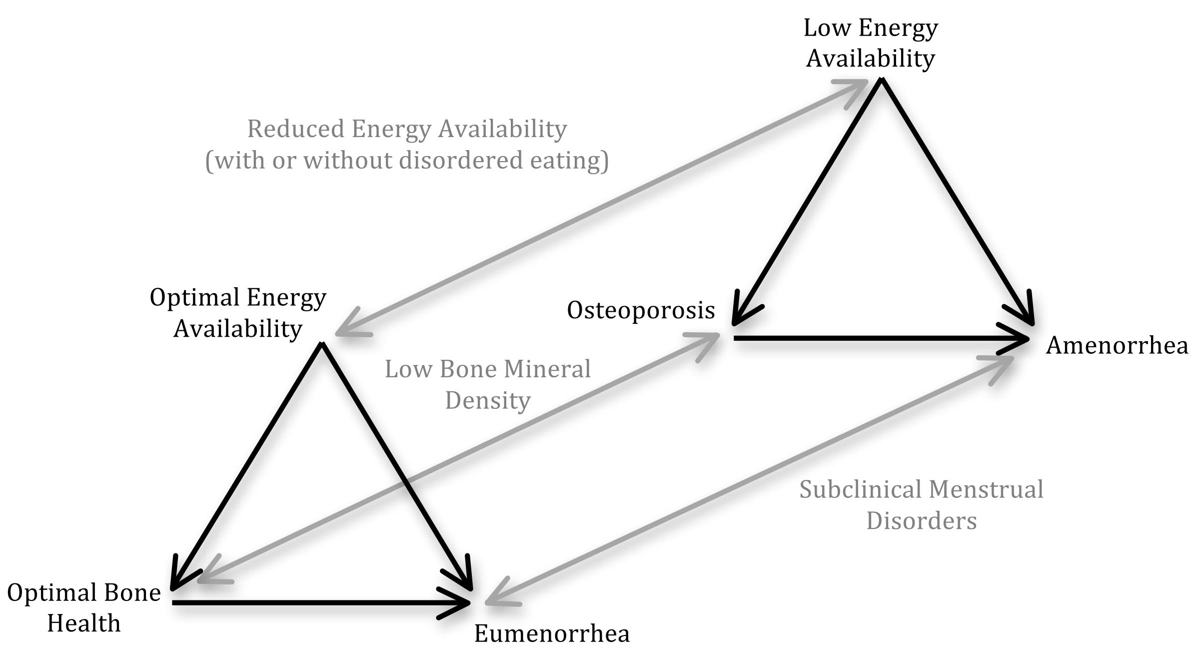

Figure 1. The Female Athlete Triad Model

In Figure 1, optimal health is represented by the triangle to the left, while the most pathological, clinical sequelae are represented by the triangle to the right. The gray lines symbolize the individual spectrums on which energy availability, menstrual functioning, and bone mineral density can be located, while the black lines demonstrate the interrelated nature of these three spectrums. Exercising women may exist anywhere along this continuum from health to pathology and can move in either direction depending on factors such as nutritional status, activity level, menstrual status, and type of activity/loading. For instance, a low energy availability often leads to suppressive outcomes on both the reproductive and metabolic axes, which when sustained for prolonged periods may result in amenorrhea and low bone mineral density. Alternatively, optimal energy availability promotes both a normal menstrual cycle and healthy bone mineral density, and furthermore, hormonal sufficiency, particularly estrogen, contributes to an optimal bone mineral density.

Many studies have been conducted to examine the prevalence of the Female Athlete Triad (Beals and Hill, 2006; Nichols et al., 2006; Hoch et al, 2007; Hoch et al, 2009; Schtscherbyna et al, 2009; Pollock et al., 2010; Torstveit and Sundgot-Borgen, 2005). These studies determined that the prevalence of the female athlete triad ranged from 0.1-15.9%, while the prevalence of women experiencing at least two of the conditions ranged from 4.0-27.0% and the prevalence of women with at least one of the conditions ranged from 16.0-60.0%. In 2010, De Souza et al. examined the prevalence of menstrual disturbances in both exercising women. Fifty percent of exercising women in the study experienced abnormal menstruation. Of the abnormal menstrual cycles, 29.2% were classified as a luteal phase defect and 20.8% were classified as anovulation (De Souza et al., 2010). Four percent of the cycles of exercising women experiencing severe menstrual disturbances were classified as oligomenorrheic, and 33.7% of the cycles were classified as amenorrheic (De Souza et al., 2010).

Two major studies have examined the prevalence of eating disorders in female athletes while classifying athletes by sport. Byrne and McLean (2002) found that eating disorders were more prevalent in exercising women than in non-athletic women and that the prevalence of eating disorders was significantly higher in thin-build athletes. The prevalence of anorexia nervosa, bulimia nervosa, and eating disorder not otherwise specified in thin build athletes was 5%, 10%, and 16% respectively and 0%, 2%, and 6.5% respectively in normal build athletes. Sundgot-Borgen and Torstveit (2004) also found that eating disorders were more prevalent in athletic women than in non-athletic controls and that eating disorders were significantly more prevalent in leanness-dependent sports than in other sports. The prevalence of eating disorders in female athletes participating in aesthetic sports was 42.2%, while the prevalence was 24% in endurance sports, 17% in technical sports, and 16% in ball game sports (Sundgot-Borgen and Torstveit, 2004). Khan et al. (2002) performed a systematic review of literature surrounding the female athlete triad and bone mineral density and found the prevalence of osteopenia ranged from 22-50% while the prevalence of osteoporosis ranged from 0-13% in female athletes.

Etiology of the Female Athlete Triad

Even before the Female Athlete Triad was a well-known clinical syndrome, investigators recognized an unnamed triad of interrelated conditions affecting the health of exercising women (Yeager et al., 1993; Nattiv et al., 1994). These three conditions included disordered eating, amenorrhea, and osteoporosis and were most commonly observed in athletes involved in sports that emphasized leanness such as distance running, ballet, and gymnastics. Researchers began to investigate the relationships between the three components of the Triad, with emphasis placed on the most severe clinical outcomes. In 1984, Drinkwater et al. examined the relationship between bone mineral content and menstrual status. They found that in groups of female athletes with matching anthropometric measurements, activity levels, and dietary intake, amenorrheic athletes had significantly lower vertebral BMD than the eumenorrheic athletes (Drinkwater et al., 1984). This demonstrated an association between menstrual disturbances and decreased BMD. Drinkwater et al (1986) demonstrated that in a group of female athletes who were all previously amenorrheic, the athletes who resumed menses experienced a significant increase in BMD while athletes who remained amenorrheic showed a continued decrease in vertebral BMD. This study also found that the athletes with a history of eumenorrhea had a significantly higher vertebral BMD (1.369 g/cm^2) than athletes with a history of menstrual disturbances (1.198 g/cm^2), even after regular menses were resumed (Drinkwater et al., 1986). This calls into question whether exercising women can ever fully recover BMD lost during a period of menstrual dysfunction. Drinkwater et al (1990) studied the relationship between previous menstrual status, current menstrual status, and BMD. The results demonstrated that the more severe a menstrual disturbance, the greater its negative effects on bone health. Women who had a history of regular menstrual cycles and were currently eumenorrheic had a lumbar density of 1.27 g/cm^2 on average while women who had a menstrual history with interspersed periods of menstrual disturbances such as oligomenorrhea or amenorrhea had a lumbar density average of 1.18 g/cm^2. Women who had never had consistent menstrual cycles had the lowest lumbar density, at an average of 1.05 g/cm^2 (Drinkwater et al., 1990).

Due to growing concern over the possible long-term health effects on the health of exercising women, the American College of Sports Medicine assembled a group of experts during the Triad Consensus Conference to discuss the connection between disordered eating, amenorrhea, and osteoporosis, and the Female Athlete Triad came into being (Yeager et al., 1993). Cobb et al. (2003) were the first researchers to confirm the existence of the Female Athlete Triad by demonstrating associations between all three of its components. The study examined female runners and found significant associations between disordered eating and menstrual disturbances, menstrual disturbances and low BMD, and disordered eating and low BMD (Cobb et al., 2003). The researchers demonstrated that the competitive female athletes had low BMD if they exhibited either disordered eating or menstrual disturbances such as oligomenorrhea or amenorrhea. Approximately 6 percent of the women who were oligomenorrheic or amenorrheic met the criteria for osteoporosis, and 48 percent met the cutoff for osteopenia (Cobb et al., 2003). This study also demonstrated that even runners who were regularly menstruating exhibited low BMD if there were any indications of disordered eating behaviors, with 26% of them meeting the criteria for osteopenia (Cobb et al., 2003).

At this time, researchers also began to realize that the Female Athlete Triad was not only a syndrome affecting elite female athletes but a condition which could be found in exercising women as well. Torstveit and Sundgot-Borgen (2005) compared a population of elite athletes with normal exercising female controls and demonstrated that there was a surprisingly high prevalence of the Triad and its components in the normal active women. While 4.3% of the elite athletes exhibited all three of the Female Athlete Triad components and 5.4-26.9% had at least two of the components, 3.4% of the normal exercising controls met all of the Triad criteria and 12.4-15.2% exhibited at least two of the conditions (Torstveit and Sundgot-Borgen, 2005). These results demonstrated that the prevalence of the Female Athlete Triad is much more widespread than once thought.

In 2007, the American College of Sports Medicine updated its Female Athlete Triad position stand to reflect a newer understanding of the syndrome. The revised position stand took into account new research conducted on the Triad's mechanism with a new emphasis placed on low energy availability as a key factor underlying both menstrual disturbances and low BMD (Nattiv et al., 2007). This 2007 position stand also introduced the idea of the Triad being a spectrum (Nattiv et al., 2007). Athletes can be located anywhere between health and disease on each of the three axes for energy availability, menstrual functioning, and bone density. This shifted the focus from the extreme, clinical manifestations of the Triad to the continuum of conditions for which many more physically active women are at risk (Nattiv et al., 2007).

Current Understanding of the Physiological and Behavioral Mechanisms Underlying the Triad

Low energy availability (EA), whether caused by low dietary intake, extensive exercise, or a combination of both, has been shown to lead to menstrual disturbances and impaired luteinizing hormone (LH) pulsatility (Loucks et al., 1998). Low EA affects LH by disturbing the pulsatile release of gonadotropin-releasing hormone (GnRH). GnRH, which is released from the hypothalamus, and is known as the "master hormone" of reproduction because it is responsible for regulating both LH and follicle-stimulating hormone (FSH) pulsatility (Tsutsumi and Webster, 2009). GnRH release is responsive to different metabolic hormones such as insulin, cortisol, growth hormone, insulin-like growth factor 1, triiodothyronine, and leptin and metabolic substrates including glucose, fatty acids, and ketones (Wade et al., 1996). When a low EA exists, the levels of these hormones and substrates are altered, causing a disruption in GnRH pulsatility and therefore, the frequency and amplitude of LH and FSH pulses. LH pulsatility can be negatively affected in only a short amount of time, with research showing that only five days of an EA reduced by at least 33% can cause disruptions in the amount and frequency of LH pulses (Loucks and Thuma, 2003). LH travels through the bloodstream to the ovaries where it stimulates the production of estrogen and therefore ovulation. LH insufficiency leads to an inadequate amount of estrogen and therefore problems with ovulation. Through this mechanism, a low EA can cause a disruption in the menstrual cycle (Williams et al., 2001a) and if a low energy intake becomes severe enough, functional hypothalamic amenorrhea can ensue (Nattiv et al., 2007).

Menstrual function exists on a spectrum from healthy to increasingly severe disturbances (Nattiv et al., 2007). Eumenorrhea is normal menstruation, defined as a menstrual cycle of 28-35 days. Subclinical menstrual disturbances include luteal phase defects (LPD) and anovulation. Women with LPD typically produce a decreased level of progesterone in the luteal phase of the menstrual cycle. Luteal phase inadequacy leads to poor endometrium quality, and therefore, ovulation occurs but implantation is faulty (De Souza and Williams, 2004). Anovulation occurs when the secretion of luteinizing hormone (LH) and follicle-stimulating hormone (FSH) are inadequate secondary to low estrogen levels and a lack of luteinization (Hamilton-Fairly and Taylor, 2003). A more dysfunctional state of menstruation is oligomenorrhea. Oligomenorrhea involves a menstrual cycle of between 36 and 90 days in length and is irregular and inconsistent (Loucks and Horvath, 1985). The most severe menstrual disturbance is amenorrhea, or the absence or cessation of the menstrual cycle for at least three months (American Society of Reproductive Medicine, 2008). Amenorrhea may be classified as either primary or secondary. Primary amenorrhea is defined as delayed menarche which has still not taken place in at the age of 15, while secondary amenorrhea is the abnormal cessation of the menstrual cycle after menarche (American Society of Reproductive Medicine, 2008).

In 1985, Bullen et al. attempted to link menstrual disturbances with physical activity. The researchers dramatically increased the exercise volume of 28 untrained, eumenorrheic women and randomly assigned them to either a weight-loss or weight-management group. Throughout the study, only four of the subjects, all of which belonged to the weight-management group, maintained menstrual normality throughout training. The rest of the participants developed luteal abnormalities or the luteal hormone surge was disrupted due to the volume of exercise (Bullen et al., 1985). After the period of increased training ended, every woman regained normal menstrual functioning, leading the researchers to conclude that vigorous exercise can lead to reversible menstrual disorders in women, especially if it is accompanied by a reduction in body weight (Bullen et al., 1985). At this point in time, however, researchers were unable to understand the mechanism behind the exercise-induced reproduction dysfunction, some believing it was the stress of exercise rather than low energy availability causing menstrual disturbances.

In 1998, De Souza et al. examined a population of sedentary and moderately exercising, regularly menstruating women to determine the frequency at which luteal phase deficiencies (LPD) and anovulation occurred in three consecutive, presumed normal menstrual cycles. Endocrine data was used to categorize cycles as ovulatory, LPD, or anovulatory, and although 90% of the cycles of the sedentary women were ovulatory, only 45% exercising women's cycles were ovulatory, with 43% of the cycles classified as LPD and 12% as anovulatory (De Souza, 1998). This study was the first to document menstrual abnormalities in seemingly regular menstrual cycles of normal length in exercising women, thus exhibiting the fact that endocrine classification of menstrual status provides a more accurate picture than self-reported data (De Souza, 1998). In addition, the exercising women in this study who presented with anovulatory cycles had lower energy availabilities than the sedentary ovulatory, exercising ovulatory, or exercising LPD women, suggesting that decreased energy availability leads to more severe menstrual disturbances on the spectrum of menstrual functioning (De Souza, 1998).

A later study conducted by De Souza et al. (2010) also sought to examine the prevalence of luteal and ovulatory disturbances in women with asymptomatic, regular menstrual cycles. The results, which confirmed those of De Souza et al (1998), showed that abnormal ovarian function presented in 52% of the presumed normal cycles of 26-35 days in exercising women compared to only 5% of those in the sedentary women. This study found that even in women who had consistent intervals between menstrual cycles, ovarian function varied considerably among cycles. This is an important finding because it may indicate that the amount of exercising women thought to be at risk for menstrual disturbances may actually be larger than currently thought.

In addition to its effects on the menstrual cycle, an estrogen deficiency also has negative effects on BMD. Estrogen is responsible for reducing bone resorption while increasing bone formation, so when it is deficient, female athletes with a low EA are at risk for a low BMD secondary to increased bone resorption (Nattiv et al., 2007; Zanker and Swaine, 1998). In addition, functional hypothalamic amenorrhea generally occurs in female athletes who are chronically undernourished, and such poor nutritional status will decrease the rate at which bone formation takes place. Consequently, bone resorption increases and bone formation decreases significantly in only five days with a reduced EA in exercising women (Ihle and Loucks, 2004). In addition, low EA plays a role in promoting bone loss through its effects on hormones such as cortisol and leptin (Ihle and Loucks, 2004).

Bone mineral density (BMD) exists on a continuum between optimal levels of bone health and pathologically low BMD and potential bone diseases, such as osteopenia and osteoporosis. Osteoporosis, which is the most severe clinical condition on the spectrum, is a syndrome in which bone strength is compromised due to poor quality of the internal mineral structure of the bones that puts the person at a significantly higher risk for fracture (Nattiv et al., 2007). The International Society for Clinical Densitometry (ISCD) determined Z-scores to be the preferred measure of BMD in women prior to menopause because it is population specific. The ISCD classified Z-scores of -2.0 or lower as "below expected range for age" and Z-scores greater than 2.0 to be "within the expected range for age" (2007). It has been shown that female athletes who participate in weight-bearing sports typically have higher BMD than athletes in lower impact or non-weight-bearing sports. Therefore, a BMD z-score of anything less than a -1.0 in a female athlete participating in a weight-bearing sport is a cause for concern (Risser et al. 1990). BMD is generally a useful indicator of an athlete's EA and menstrual status, both in the present and over her cumulative past. BMD Z-score can be used to not only quantify an athlete's current level of bone health but also look at trends compared to age-matched individuals and determine in which direction the athlete is progressing along the bone health spectrum (Nattiv et al., 2007). This pathway from low energy availability to menstrual disturbances and decreased BMD gives rise to the Female Athlete Triad.

Energy Availability

Energy availability (EA) is dietary energy intake minus exercise energy expenditure adjusted for lean body mass (Loucks and Callister, 1993). When exercise energy expenditure is greater than dietary energy intake, an energy deficit occurs. In response to a chronic energy deficit, energy is diverted away from unnecessary functions, preserving energy for only vital body processes that sustain life (De Souza and Williams, 2004). Bodily processes such as thermoregulation, cellular maintenance, and locomotion are all considered vital processes to maintain during an energy deficit, but processes such as reproduction and growth (De Souza and Williams, 2010) are less necessary for survival and are thus suppressed. This compensatory mechanism is enough to achieve energy balance within the body, but physiological function and general health is impaired.

EA may be reduced through several different mechanisms, either intentionally or unintentionally, and Loucks, et al (2011) identified the three origins of negative energy balance. The first is disordered eating, which lies on a spectrum ranging from severe to subclinical ((Sundgot-Borgen and Torstveit, 2010). Clinical eating disorders are classified by the American Psychiatric Association in the DSM-IV and include anorexia nervosa, bulimia nervosa, and the eating disorder not otherwise specified (EDNOS) category (Nattiv et al., 2007). These disorders present with serious mental illness and are typically associated with pathological health consequences (Loucks, Kiens and Wright, 2011). Subclinical eating disorders do not meet the strict criteria to be considered one of the three severe clinical disorders but still present with significant mental issues, weight concerns, and disordered eating behaviors (Beals and Manore, 1994). For instance, an athlete with subclinical anorexia may show signs of anorexia nervosa but may not restrict enough to be diagnosed as anorexic (Beals and Manore, 1994). An athlete with subclinical bulimia nervosa may exhibit binging and purging behavior but not often enough to meet the criteria for bulimia nervosa (Beals and Manore, 1994). Athletes with subclinical disordered eating generally exhibit the same type of psychological traits as those with clinical eating disorders such as high achievement orientation, perfectionism, and obsessive-compulsive tendencies, yet these are not accompanied by the emotional distress and psychopathologies characteristic of severe eating disorders (Leon, 1991).

The second origin of negative energy balance is intentional and rational but mismanaged attempts to decrease body weight for the purpose of excelling in a particular athletic event (Loucks et al., 2011). This mechanism could possibly include behaviors associated with disordered eating such as fasting, vomiting, or the use of pills or laxatives because these techniques have become engrained in some types of sporting culture (Loucks et al., 2011). This origin of energy deficiency differs from eating disorders in that it occurs without the psychological issues associated with anorexia nervosa, bulimia nervosa, EDNOS, and subclinical disordered eating.

The third origin of low EA is inadvertently failing to compensate for an energy deficit (Loucks et al., 2011). This may occur if an athlete increases training volume but does not modify her diet accordingly to meet the higher energy needs due to increased expenditure through exercise. Some athletes are not as responsive to an energy deficit and fail to compensate for the energy they expend during exercise. Researchers have demonstrated that energy deficits created via exercise do not increase hunger as do deficits created via food deprivation (Truswell, 2001). For this reason, appetite cannot be used as an effective indicator of energy requirements in many female athletes. In addition, diet composition is associated with the amount of dietary compensation that occurs in exercising individuals. Stubbs et al. (2004) demonstrated that lean men who consumed a diet low in fat and high in carbohydrate were less likely to compensate for their exercise energy expenditure than men who consumed a high fat diet, although neither group of men fully compensated for their energy expenditure. Another study conducted by Horvath et al. (2000) confirmed these results in male and female endurance-trained runners. Athletes consuming a high carbohydrate diet with about 17% of energy from fat exhibited a reduced energy intake, but when the amount of fat in their diet was increased to 31% of total energy, energy intake and availability were also increased by approximately 30% with reductions in their intake of carbohydrates (Horvath et al., 2000).

Evidence has shown that energy and macronutrient intake influences thyroid hormone status which then plays a role in determining resting energy expenditure (REE) (Wimpfheimer et al., 1979; Burger et al., 1980; Gardner et al., 1979; Rosenbaum et al., 2000). One of these thyroid hormones is 3,5,3'-triiodothyronine (T_3), and this hormone is typically used as an indicator of energy deficiency because decreases in its concentrations initiate energy conservation to restore energy homeostasis in cases of starvation and underweight individuals (Burger et al., 1980; Gardner et al., 1979). Decreases in T_3 concentration initiate energy conservation to restore energy homeostasis. Onur et al. (2005) demonstrated low plasma T_3 concentrations in women with anorexia nervosa and that these low levels were also associated with decreased REE. In addition, anorexic women who gained weight exhibited increases in T_3 concentrations which increased REE independently of fat free mass Onur et al., 2005). Loucks et al (1992) found that low T_3 levels existed in amenorrheic female athletes but not in their eumenorrheic counterparts. Because of the established role of T_3 as an indicator of energy deficiency, this suggests that amenorrheic women are experiencing an energy deficit compared to eumenorrheic women who we would assume are in energy balance. Thus, T_3 is a marker of chronic energy deficiency wherein the body may begin to preserve vital bodily functions, ceasing menstruation. In a subsequent study, Loucks and Callister (1993) manipulated the energy availability of eumenorrheic women by increasing exercise volume without a corresponding increase in dietary intake, and this induced low-T_3 syndrome in a matter of four days. They were also able to prevent the low T_3 levels by increasing the dietary intake of the subjects in accordance with their exercise volume, thereby preventing energy deficits (Loucks and Callister, 1993). This demonstrates that it is not dietary intake or exercise energy expenditure alone that leads to menstrual disturbances but rather overall energy availability. Additionally, Loucks and Callister (1993) did not find any differences in T_3 levels based on the volume or intensity of exercise, suggesting that an energy deficit is responsible for menstrual dysfunction rather than the actual activity or the stress of exercise. Supporting this idea, Loucks et al (1998) found that the stress of exercise alone had no effect on LH pulsatility, while low energy availability reduced LH pulse frequency by 10% during the waking hours and by 36% during waking and sleeping hours. These findings also suggested that an energy deficit due to an insufficient dietary intake has more of an effect on LH pulsatility than a deficit achieved through excessive energy expenditure (Loucks, Verdun, and Heath, 1998). In 2003, Loucks and Thuma manipulated the energy availability of regularly menstruating women in order to determine the threshold of energy availability at which a disruption in LH pulsatility would occur. There were four groups of women who all performed 15 kcal/kg LBM of 70% maximum oxygen uptake exercise for five days while their energy intake was controlled at 45, 30, 20, and 10 kcal/kg LBM per day, respectively. The women in the 45 kcal/kg LBM group were thought to be in energy balance, while the women in the 30, 20, and 10 kcal/kg LBM group were thought to be in energy restriction (Loucks and Thuma, 2003). It was demonstrated that an energy availability of 30 kcal/kg of lean body mass per day left LH pulsatility unaffected, but energy availabilities below this threshold negatively affected the frequency of LH pulsation (Loucks and Thuma, 2003). This indicates that menstruation is only affected below a threshold of energy availability which is representative of a negative energy balance (Loucks and Thuma, 2003).

Using a monkey model, Williams et al. (2001a) were able to both induce and reverse exercise-related menstrual disturbances in monkeys, demonstrating the link between low energy availability and menstrual function. The researchers increased the exercise volume of eight monkeys, all eight of which developed amenorrhea due to low energy availability. Four of the monkeys were then fed supplemental calories and reestablished normal menstrual cycles in response to the adequate dietary intake. The amount of energy consumed was correlated with the rapidness with which normal menstruation was restored, and T_3 levels were dramatically decreased (27%) during the period of restricted dietary intake while its levels rose significantly (18%) during the return to regular menstrual cycles. Williams et al (2001b) also used the monkey model to document the longitudinal hormonal changes that occur during the development of exercise-induced amenorrhea, measuring LH, FSH, estradiol, and progesterone levels and menstrual cyclicity. Although the results varied significantly between individuals, abrupt changes such as decreases in reproductive hormone concentrations occurred within one or two cycles before the complete termination of menstruation, and this study enabled researchers to establish the order at which reproductive changes occur in response to low energy availability (Williams et al., 2001b). It was demonstrated that exercise-induced menstrual dysfunction originates with down-regulation of the gonadotropin releasing hormone (GnRH) generator. GnRH suppression leads to a longer cycle length, a longer follicular phase, decreased LH concentration during the early part of follicular phase, decreased average and peak luteal progesterone concentrations, and the decreased levels of LH, FSH, estradiol, and progesterone, with all of these effects being evident in the cycle before the induction of amenorrhea (Williams et al., 2001b).

Cognitive Restraint

Origin of Cognitive Restraint

Dietary Cognitive Restraint (CR) is defined as the conscious restriction of food intake in an effort to achieve or maintain a certain body weight. This concept was originally introduced by Herman and Mack (1975) to explain dietary intake discrepancies in college aged women with normal body weights. Previous investigators (Nisbett, 1968) supported the premise that "external" cues had a larger amount of influence on dietary intake in obese eaters whereas the dietary intake of normal weight eaters was more impacted by "internal" cues from within the body and likely controlled by the hypothalamus. Presumably, this would mean obese eaters have a higher dietary intake than normal weight eaters, but in reality, researchers found that there was a large degree in variability in dietary intake in both overweight eaters and in normal weight eaters. Several theories were proposed to explain this including the weight "set-point" theory wherein an individual manipulates dietary intake to achieve an "ideal" weight (Herman and Mack, 1975). College aged women are especially susceptible to cultural expectations of "ideal" weight, and this is where CR applies to dietary intake. Herman and Mack (1975) found that women with low CR typically exhibited "internal" regulation of dietary intake, meaning that their eating behavior was predominantly mediated by physiological factors such as hunger and satiety cues within the body. Contrary to this, women with high CR exhibited higher levels of "external" regulation, making them susceptible to the attractiveness of food cues such as the sight, smell, or thought of food (Papies, Stroebe, and Aarts, 2008). Seeing these trends, Herman and Mack (1975) concluded that CR is a better predictor of eating behavior than other factors such as body weight.

Measurement of Dietary Cognitive Restraint

CR can be measured through the use of the Three Factor Eating Questionnaire (TFEQ). This questionnaire was designed by Stunkard and Messick (1985) with subscales to measure dietary restraint, disinhibition, and hunger, three dimensions that influence dietary patterns. There are several different scales for measuring dietary restraint but the TFEQ is typically considered the most robust measure (Gorman and Allison, 1995; Williamson et al., 2007; Laessle et al., 1989). The TFEQ is included in Appendix 1 with questions representing each of the different subscales highlighted accordingly.

Flexible and Rigid Cognitive Dietary Restraint

In 1991, Westenhoefer determined that the restraint scale on the TFEQ was not homogeneous and should be differentiated into two different types of restraint: flexible and rigid. These different subtypes of restraint involve different cognitions and behaviors and are typically related to the women's level of disinhibition. In rigid control, women exhibit a very "all-or-nothing" attitude about dieting and eating, and disinhibition is generally high (Westenhoefer, 1991). According to Westenhoefer (1991), eaters with rigid control frequently diet but fail to be deliberate with their dietary intake. These women struggle to eat small portions, eat slowly, or hold back at meals. Additionally, they place a greater emphasis on weight fluctuations than on changes in their figure and avoid foods that they have deemed "forbidden" (Westenhoefer, 1991). Rigid restraint seems to be associated with more susceptibility to eating problems such as bulimia and binge eating behaviors and has been shown to be a predictor of greater food intake and greater body weight (Westenhoefer, et al., 1994; Shearin, et al., 1994). The other type of restraint mentioned by Westenhoefer (1991) is flexible restraint. Women with this type of dietary restraint tend to have a more balanced view on dieting and eating (Timko, 2007). Flexible restraint is a more dynamic view on food intake in which "forbidden foods" are eaten in limited quantities but without the guilt that may occur in women with rigid constraint (Westenhoefer, et al., 1999). Women with flexible control are generally more successful dieters, and the measure can be used in weight loss programs as a predictor of success (Westenhoefer, 2001). The downside of flexible constraint is that although the measure is inversely related to body weight, it has also been shown to have an association with anorexia nervosa diagnosis (Shearin, et al., 1994).

Implications of High Cognitive Dietary Restraint

Because records of dietary intake are subject to a large amount of reporting error, it is still unclear whether the actual dietary intake of exercising women varies with respective levels of CR. Some studies have demonstrated that women with high CR report significantly lower dietary intake than women with normal levels of CR. In addition, some studies have demonstrated that the amount of energy expenditure through physical activity differs in women with varying levels of cognitive restraint.

Tuschl et al. (1990) measured the average total energy expenditure in women who had both high and low levels of CR. They demonstrated that restrained eaters exhibited higher relative body weights, but their self-reported energy consumption was approximately 410 kilocalories per day less than women with low CR (Tuschl et al., 1990). In addition to this, the eaters with high CR had adjusted energy expenditures which were approximately 620 kilocalories per day less than the low CR member (Tuschl et al., 1990). Indicators of starvation (including T_3) were within normal ranges, and there was no weight change in the subjects, so it seems that the lower energy expenditure results are more an indication of diminished caloric requirements than the body's adaptation to a short-term decrease in dietary intake (Tuschl et al., 1990). Women in the restrained group consumed a lower percentage of their diet from fat than women in who were classified as unrestrained eaters (Tuschl et al., 1990).

An investigation by Klesges et al. (1992) also compared the differences between men and women with a high level of dietary restraint and those with a low level in regards to diet, activity, and body weight. It was demonstrated that the eaters with high amounts of CR had comparable activity levels to their low-restraint counterparts, but a significant difference was observed in the amount of food consumed by the two groups (Klesges et al., 1992). The high CR group consumed significantly fewer kilocalories per pound of body weight, but a larger portion of their dietary intake was fat (Klesges et al., 1992). The men and women with high CR had higher body masses, and although weight gain in the men was related to weight at baseline, weight gain in the women was associated with high CR scores (Klesges et al., 1992).

Women with high CR scores also reported consuming fewer total calories in a study conducted by French et al. (1994). The purpose of this investigation was to examine differences between dieting and non-dieting individuals in regards to their food preference and intake and activity levels. This study classified individuals by their CR score using the TFEQ, Herman and Polivy's Restraint Scale, and questionnaires on current dieting behaviors. Women who had high CR scores were considered chronic dieters, and self-reported data indicated that they consumed fewer total calories, fewer calories from "sweets", and "sweets" less often. In addition, dieting women had energy expenditures from physical activity which were approximately twice that of non-dieting women.

Laessle and colleagues (1989) sought to extend the concept of CR past a laboratory setting and into everyday life and eating behaviors. After analysis of seven-day food records for 60 women, the researchers found that women with high levels of CR consumed approximately 400 kilocalories per day less than women who were members of the low CR group (Laessle et al., 1989). There were also differences in the actual eating pattern of women in the different groups. High CR eaters consumed protein as a greater percentage of their diet and made an effort to avoid foods which were high in carbohydrates or fat, instead choosing foods which were low calorie and "healthy" (Laessle et al., 1989). This study demonstrated that the concept of cognitive restraint was not limited to a controlled, laboratory environment but could also be useful in a population of free-living individuals (Laessle et al., 1989).

Differences have been shown in the menstrual status and characteristics of women with different levels of CR. High CR can lead to reproductive dysfunction such as amenorrhea, oligomenorrhea, short menstrual cycle, short luteal phase, and anovulation (McLean and Barr, 2003; Vescovi et al., 2008; Barr et al., 1994; Schweiger et al., 1992, Williams, Flecker and

Galucci, 2006; Hontscharuk et al., 2004). McLean and Barr (2003) conducted a study in which a large population of university women were grouped by CR levels and compared based on their dietary behaviors, lifestyle, personality characteristics, and menstrual status. There were significant differences between the high CR women and the low CR women in many different variables, including those addressing menstrual status. Compared to women categorized as having low CR, women with high CR had greater exercise volumes (4.6 ± 5.3 vs. 3.2 ± 3.5 hours per week) and were more likely to be vegetarian (14.5 vs. 3.7%), have a previous eating disorder (13.7 vs. 1.2%), be currently dieting (80.3 vs. 15.3%), and have lower self-esteem and higher perceived stress scores. Women with high CR scores were much more likely to have menstrual disturbances (34.7 vs. 17.0%) than women with either low or medium CR scores, and the researchers found that CR was the only variable capable of differentiating women by menstrual status.

In a previous report by this lab, it was shown that 50% of the women in the high CR group reported eumenorrhea whereas 74% of the women with normal CR reported eumenorrhea (Vescovi et al., 2008). In addition, a pattern was seen across the spectrum of CR levels, the lowest quartile of CR scores had the greatest proportion of eumenorrheic women (Vescovi et al., 2008). Women with lower CR scores also had higher E1G and PdG area under the curve measures, indicating that they had normal exposure to estrogen and progesterone (Vescovi et al., 2008). Vescovi et al (2008) also demonstrated that exercising women with high CR typically had lower total body BMD and that the higher the CR, the lower the BMD (Vescovi, 2008). This is a finding that is consistent with other studies which demonstrate that women with high CR tend to have significantly lower BMD than women with normal levels of CR, likely due to decreased energy availability (Vescovi et al., 2008; Barrack et al., 2008; McLean et al., 2001; Bedford et al., 2010; Van Loan and Keim, 2000).

Research has shown that premenopausal women who demonstrate a high CR typically exhibit more chronic dieting and weight loss cycles than their normal CR counterparts (Van Loan and Keim, 2000). Weight loss cycles are defined as a period of highly controlled food intake in an effort to reduce body weight followed by a period of disinhibition and weight regain (Bacon et al., 2004). It has also been demonstrated that chronic dieting behavior has a major impact on bone mineral content (BMC). A study on obese premenopausal women showed that although this particular population was expected to have a decreased risk for low BMC due to their higher body weight, obese women with a history of chronic dieting actually had a significant occurrence of osteoporosis and osteopenia, at about 30.8% (Bacon et al., 2004). This study also found important negative associations between the number of weight loss cycles and BMC. Given the lack correlation between BMC and other dietary factors and biochemical markers, it could be concluded that these findings were due to previous weight cycling and not current behaviors. Other research found that the amount of change that occurs in both BMD and BMC was proportional to the amount of weight lost in a weight loss cycle (Fogelholm, 2001). A randomized, controlled trial that took place over a period of 3-6 months found that a weight reduction of 10-14% in premenopausal women correlated with a 1-4% decrease in total body and lumbar spine BMD (Fogelholm, 2001). This same group of women showed only partial restoration to pre-cycle BMD levels when about 63% of the weight lost had been gained back (Fogelholm, 2001). All of these associations indicate that a high CR may be a predictor of a history of weight cycling and the associated risk for decreased BMD in premenopausal women.

Vescovi et al. (2008) showed that women in the highest quartile of CR scores showed a suppressed resting energy expenditure (REE) and ratio of actual REE compared to the Harris-Benedict predicted REE (REE/pREE), suppressed fasting total triiodothyronine concentration (TT_3), and elevated fasting ghrelin concentration. This study, however, did not directly examine the role of disinhibition in regulating anthropometric, body composition, energetic, metabolic, and reproductive characteristics in exercising women and the investigators could not conclude whether the women with high CR successfully or unsuccessfully restrained their food intake, leading to the development of energy conservation mechanisms.

Disinhibition

Along with its measurement of CR, the TFEQ also has a scale for the quantification of a characteristic known as disinhibition (Stunkard and Messick, 1985). Disinhibition represents the reversal of inhibition of dietary intake and reflects the tendency to over-eat or eat opportunistically in an obesigenic environment, countering the restriction of food intake (Bryant et al., 2007). High levels of CR can place a cognitive burden on dieters when weight loss goals are given high priority over the temptation to indulge (Kronick et al., 2011). If this burden becomes too great for the dieter to withstand, the importance of meeting weight loss goals is replaced by the indulgence in a "forbidden food" as the top priority, and this will typically lead to the release of restraint and the initiation of a disinhibitory event to result in binge eating (Kronick et al., 2011). Disinhibitory events may be caused by a number of cognitive processes. It has been suggested that restrained eaters set boundaries on their caloric consumption, and once these boundaries are crossed, dieters release their restraint and participate in disinhibited eating (Herman and Polivy, 1984; Lowe et al., 1991; Lowe, 1993). Another cognitive process that may lead to disinhibitory eating is the dieter's formation of defeatist attitudes about the ability to actually withstand the temptation posed by a "forbidden food" (Ogden and Wardle, 1991). If a dieter does not believe that they possess the ability to deny themselves then the pleasure of eating a "forbidden food", they will permit themselves to release restraint (Ogden and Wardle, 1991). In addition, a cognitive process that may lead to a disinhibitory event is the activation of compensatory beliefs (Knäuper et al., 2004). A compensatory belief is the idea that the negative effects of disinhibited eating can be neutralized by the positive effects of some type of compensating behavior such as skipping a meal or exercising excessively (Kronick et al., 2011). In essence, compensatory beliefs enable dieters to have the "best of both worlds" because they justify the immediate pleasure of consuming a high-fat or high-calorie indulgence with the promise of compensation for this indulgence at a later time (Kronick et al., 2011). Research has confirmed the idea that dieters form compensatory intentions when they are forced to choose between tempting, "unhealthy" food and less enticing "healthy" food and that dieters who form more compensatory intentions have a greater likelihood of giving into temptation (Kronick et al., 2011). This research, however, examined choice of a "forbidden food" and not actual consumption, so this concept needs to be further investigated in order to determine whether a greater amount of compensatory belief actually translates to a greater intake of energy.

Conclusion

Low energy availability, in combination with menstrual disturbances and/or low bone mineral density or alone, is a significant problem for female athletes. One of the potential origins of low energy availability is a high CR, and for this reason, future research should focus on establishing a causal relationship between this eating behavior trait and low energy availability. A novel approach would be to examine CR as a nonhomogeneous variable and assess disinhibition to describe successful vs. unsuccessful restraint in inducing low energy availability. The CR and disinhibition subscales in combination may represent psychometric tools useful for exercising women as well as coaches and trainers to identify women at risk for low energy availability and potentially, the development of other clinical outcomes related to the Female Athlete Triad.

Chapter 2

Introduction

Subclinical disordered eating behavior is highly prevalent in premenopausal exercising women and contributes to the development of energy deficiencies in this population (Nattiv et al., 2007). If these energy deficiencies becomes severe enough, they could result in the pathological health consequences of the Female Athlete Triad, a condition marked by low energy availability (EA), severe menstrual disturbances, and low bone mineral density (BMD) (Nattiv et al., 2007). Low EA, whether through an increase in exercise energy expenditure or a reduction in energy intake, causes the body to initiate the conservation of energy stores, reserving fuel for only the most vital physiological processes. Reproductive function is not considered essential for life, so it is suppressed as one of these energy conservation mechanisms (De Souza and Williams, 2010).

Suppression of reproductive functioning occurs through the disruption of gonadotropin releasing hormone (GnRH) release from the hypothalamus. GnRH is known as the "master hormone" of the reproductive system, and its pulsatility impacts the pulsatile release of both luteinizing hormone (LH) and follicular stimulating hormone (FSH) (Tsutsumi and Webster, 2009). During a period of low EA, the release of GnRH is interrupted, and subsequently, the frequency and amplitude of LH and FSH pulses are also disrupted. This leads to an inadequate amount of estrogen production and release, and menstrual distubances, both subclinical (luteal phase defects and anovulation) and severe (oligomenorrhea and functional hypothalamic amenorrhea), occur as a result. Estrogen deficiencies also have a dramatic effect on BMD. Normally, estrogen reduces bone resorption and increases bone formation, but if low EA has led to decreased estrogen, female athletes are at risk for low BMD secondary to a disruption of the normal balance between resorption and formation (Nattiv et al., 2007). To this end, low energy availability is a key factor underlying clinical outcomes which are detrimental to reproductive and bone health.

Dietary cognitive restraint (CR) is the conscious restriction of food intake in an effort to achieve or maintain a certain body weight. A high CR can contribute to the development of an energy deficiency through its effects on energy intake, putting exercising women with a high CR at risk for the development of the Female Athlete Triad. Several studies have linked high CR with reproductive dysfunction, such as amenorrhea, oligomenorrhea, and anovulation (McLean and Barr, 2003; Vescovi et al., 2008; Barr et al., 1994; Schweiger et al., 1992), and decreased BMD (Vescovi et al., 2008; Barrack et al., 2008; McLean et al., 2001; Bedford et al., 2010; Van Loan and Keim, 2000) in premenopausal exercising and sedentary women. In a previous report (Vescovi et al., 2008), a high CR was associated with a suppressed resting energy expenditure (REE) and ratio of actual REE compared to the Harris-Benedict predicted REE (REE/pREE), suppressed fasting total triiodothyronine concentration (TT_3), and elevated fasting ghrelin concentration. This study, however, did not directly examine the role of disinhibition in regulating anthropometric, body composition, energetic, metabolic, and reproductive characteristics in exercising women or whether women with high CR successfully or unsuccessfully restrained their food intake, leading to the development of energy conservation mechanisms.

Disinhibition is a counter-regulatory response to the restriction of food intake and represents the tendency to over-eat or eat opportunistically in an obesigenic environment. Whether women successfully or unsuccessfully restrain likely depends on their level of disinhibition. We would expect that women with normal disinhibition would demonstrate successful restraint because they would experience fewer incidences of overeating which counter their usual restraint. Women with high disinhibition would likely exhibit unsuccessful CR because of their tendency to reverse inhibition and counter-regulate their dietary restraint, preventing the development of a chronic energy deficit. To date, the association between CR, disinhibition, and energetic status in premenopausal exercising women is unclear.

The purpose of this study is to compare anthropometric, body composition, energetic, metabolic, and reproductive characteristics in exercising women when categorized by CR and disinhibition status. We hypothesize that the High CR and Normal Disinhibition group would have lower EA compared to the High CR and High Disinhibition group. Additionally, we hypothesized that the High CR and Normal Disinhibition group would have a lower energy intake and higher exercise energy expenditure than the High CR and High Disinhibition group. A third hypothesis was that the High CR and Normal Disinhibition group would have lower REE, corroborated by lower TT_3 and higher ghrelin compared to the High CR and High Disinhibition group. If we find that high CR and normal disinhibition are related to a chronic energy deficiency and simultaneous metabolic hormone adaptations, this would indicate that these eating behavioral traits generally lead to the chain of energy-conserving mechanisms found in the Female Athlete Triad. In summary, the CR and disinhibition subscales in combination may represent psychometric tools useful for exercising women as well as coaches and trainers to identify women at risk for an energy deficiency.

Chapter 3

Materials and Methods

Experimental Design: This is a cross-sectional study comparing exercising women aged 18-35 years with high CR and normal disinhibition (n=27), high CR and high disinhibition (n=14), and normal CR and normal disinhibition (n=44) with respect to anthropometric, energetic, metabolic hormone, and psychological characteristics. Participants were retrospectively grouped according to their CR and disinhibition scores obtained from the TFEQ. Subjects with a score of 11 were classified as having a high CR whereas subjects with a score of 8 were classified as having a high disinhibition score. In order to be considered an "exercising" woman, the participants needed to partake in at least 2 hours of purposeful exercise each week and have a VO_2 max of at least 40 ml/kg/min (Saltin and Astrand, 1967). Participants who were eumenorrheic (normally menstruating) were monitored for the length of a complete menstrual cycle while women who were experiencing menstrual disturbances were monitored for a least a 28-day monitoring period. Classification by menstrual status involved evaluating self-reported menstrual history, confirmation of the presence of a luteinizing hormone (LH) peak, and quantification of daily urinary ovarian steroid metabolites, estrone-1-glucuronide (E1G) and pregnanediol glucuronide (PdG). Energetic status was determined via measurement of REE. A blood sample was collected following the REE test and assayed for total triiodothyronine and ghrelin concentrations. This investigation includes baseline data from a cross-sectional study designed to assess cardiovascular status in exercising women and data from the baseline period of a prospective study designed to assess the effects of a 12-month intervention of increased caloric intake on indices of bone health and menstrual status in exercising women with menstrual disturbances vs. exercising women with ovulatory cycles.

Participants: To be eligible for the study, the women needed to meet all of the following criteria: (1) between the ages of 18 and 35, (2) good health status as determined by a medical professional, (3) free of any chronic medical conditions such as hyperprolactinemia or thyroid disease, (4) stable menstrual status for the preceding 3 months, (5) at least two hours/week of purposeful exercise and a VO_2 max≥40 ml/kg/min, (6) non-smoker, (7) stable weight status for the preceding 3 months and not presently dieting, (8) no hormonal therapy treatment for the last six months, (9) no current or past clinical diagnosis of eating disorders, and (10) no other contraindications that would prevent study participation. This study was approved by Institutional Research and volunteers signed an approved Informed Consent document.

Study Time Period: Participants completed psychometric measurements of eating attitudes and behaviors. This appointment was followed by a REE test and a fasting blood sample for the measurement of TT_3. Eumenorrheic (menstruating, cycle length 26-35 days) women were followed for one complete menstrual cycle, oligomenorrheic (inconsistent and irregular cycle length of 36-90 days) women were followed up to 90 days, and amenorrheic (no menses for at least 90 days) women were followed for one 28-day monitoring period.

Group Categorization: Participants were retrospectively characterized into three groups based on CR and disinhibition scores. The groups included: high CR and normal disinhibition (n=27), high CR and high disinhibition (n=14), and normal disinhibition and normal CR (n=44).

Anthropometric Data: Total body mass was measured to the nearest 0.1 kg on at least two occasions (each measurement within a four week period), and the mean of these measurements is presented. Participants were expected to stay within ±2.5 kg of their first body mass measurement and were weighed in shorts and a t-shirt. Height was measured to the nearest 1.0 cm. Body mass index (BMI) was calculated as the average body mass divided by height squared (kg/m^2). Body composition was assessed using dual-energy x-ray absorptiometry (DXA). Subjects were scanned on either a GE Lunar Prodigy (n=50, enCORE 2002 software version 6.50.069), a GE Lunar iDXA (n=27, enCORE 2008 software version 12.10.113) or a Hologic QDR4500 DXA scanner (n=8, Hologic Inc., Bedford, MA). Consistent with the International Society of Clinical Densitometry guidelines, a cross calibration study was performed to remove systematic bias between the systems. For the cross calibration study between the Lunar Prodigy and Lunar iDXA, 14 participants were scanned in triplicate on both machines. The values for body composition obtained on each scanner were found to be highly correlated with no significant difference between the population mean values. For the cross calibration study between the Hologic QDR4500W and the Lunar iDXA, 32 participants were scanned in duplicate on both machines. Equations were derived using simple linear regression to remove biases, and body composition values obtained from both the Lunar Prodigy and the Hologic QDR-4500W were calibrated to the Lunar iDXA.

Three Factor Eating Questionnaire (TFEQ): The TFEQ is a questionnaire that measures three dimensions of human eating behavior: (1) CR, (2) disinhibition, and (3) hunger (Stunkard & Messick 1985). This questionnaire was administered once during the study primarily to identify women with different eating phenotypes related to CR and disinhibition. The volunteers were categorized into three groups based on their CR and disinhibition scores: (1) High CR + High Disinhibition, (2) High CR + Normal Disinhibition, and (3) Normal CR + Normal Disinhibition.

Dietary Cognitive Restraint (CR) and Disinhibition Scores: CR and Disinhibition scores were obtained from the TFEQ (Stunkard & Messick 1985), which was completed once during the study. A cut-off of greater than or equal to 11 on the CR subscale represents an elevated value and is indicative of subclinical disordered eating behavior (Stunkard and Messick, 1988).

The rationale for the cut-off of greater than or equal to 8 on the Disinhibition subscale was based on statistical analyses completed on a larger sample of women from our lab (n=145) determining the 75th percentile on this subscale.

Energy Availability (EA): EA was operationally defined as dietary energy intake minus exercise energy expenditure relative to kilograms of lean body mass (EA = (EI – EEE)/LBM) (Loucks and Callister, 1993) and calculated using the data described above for dietary energy intake, exercise energy expenditure, and anthropometrics. Dietary energy intake assessed from 3-day diet logs during week 3 of the study period or the average of several 3-day diet logs completed during the study period provided the dietary energy intake to compute EA. Exercise energy expenditure assessed during week 3 of the study period provided the exercise energy expenditure to compute EA. Lastly, lean body mass assessed during the study period provided the lean body mass to compute EA.

Dietary Energy Intake: Dietary energy intake was assessed on two occasions during the study from three day nutritional logs recorded for two weekdays and one weekend day, as previously described (De Souza et al. 2007a). Three day nutritional logs recording food intake have been demonstrated to provide comparable data to seven day records in women who may underreport their food intake, including lean women (Goris & Westerterp 1999). Participants were recommended to weigh (ECKO Kitchen Scale, World Kitchen, LLC, Rosemont, IL, USA) or measure (using standard measuring cups/tools) all food and beverages consumed in detail. Subjects were also asked to record time and location of every eating episode. On-site registered dietitians met with the subjects to instruct them to accurately record dietary energy intake. The nutrient data from the three day logs were coded and analyzed using the Nutrition Data System for Research (NDSR 2008 Version; University of Minnesota; Minneapolis, MN, USA). Daily dietary energy intake (kJ/day) over the three day recording periods was expressed as the mean value during the study.

Resting Energy Expenditure (REE): REE was measured on a single occasion during the study. REE was determined by indirect calorimetry using a ventilated hood system (SensorMedics Vmax Series, Yorba Linda, CA, USA) by methods previously published in detail (De Souza et al., 2008). In brief, volunteers arrived between 0600 and 0900 in a 12 hour post absorptive state having not exercised or ingested caffeine within 24 hours, and within 90 minutes after awakening. Before conducting the REE analysis, weight (kg) and age (yr) were recorded, and predicted REE (pREE; kJ/day) was calculated using the Harris-Benedict equation (Harris & Benedict, 1919). Participants were instructed to lie quietly and awake in a supine position for 45 minutes, followed by 45 min with the ventilated hood placed over their head. Oxygen consumption (VO_2; mL/min) and carbon dioxide production (VCO_2; mL/min) were measured every 30 s. To calculate REE, data for VO_2 and VCO_2 were only used if steady state was attained. REE was calculated using the Weir equation (Weir, 1949). Predicted REE (pREE; kJ/day) was calculated using the Harris-Benedict equation (Harris & Benedict 1919). A ratio of the measured REE in the laboratory to predicted REE (REE/pREE) was calculated.

Energy Status: Energy status was defined using an objective laboratory-based measure, the measurement of REE, to identify individuals who experience energetic adaptations to an energy deficiency (De Souza et al. 2007b; De Souza et al. 2008; Myburgh, Berman, Novick, Noakes, & Lambert 1999). Reductions in REE have been observed in several studies examining exercising women who present with amenorrhea (De Souza et al. 2008). We compared lab assessed REE to a prediction equation for REE to estimate how much each individual's measured REE deviated from the predicted REE. In women with anorexia nervosa (Konrad et al. 2007; Melchior et al. 1989; Polito et al. 2000), the majority of data published utilized the Harris-Benedict equation (Harris et al. 1919) to predict REE, and as such, we determined that this equation was most useful for our purposes. A previous study by our lab group provided our reasoning for using the Harris-Benedict equation over the Cunningham equation (De Souza et al.

2008). In brief, it has been shown during periods of low body weight, and prior to refeeding in anorexic women (Konrad et al. 2007; Melchior et al. 1989; Polito et al. 2000), that a reduced ratio of measured REE to Harris-Benedict predicted REE (Harris et al. 1919) of 0.60-0.80 is often reported. The Cunningham equation has not been used in anorexic women. We have previously published data using operationally defined energy deficiency as a ratio of REE/pREE less than 0.90 (De Souza et al. 2007a; De Souza et al. 2007b; De Souza et al. 2008). We chose to use this REE/pREE cut-off (<0.90) in the current study as our operational definition of energy deficiency to best discriminate the exercising women who may present with an energy deficiency from those who are energy replete.

Blood Sampling and Storage: Blood samples were collected between 0730 and 1000 h on a single occasion during the study, stored and processed as previously described by (De Souza et al. 2007). For menstruating women, blood samples were taken during the early follicular phase at days 2-6 of the menstrual cycle, and for women with amenorrhea or oligomenorrhea, blood samples were taken during days 1-6 of the 30 day monitoring period. The volunteers were instructed to abstain from exercise or food consumption within 12 hours of the blood sample's collection. Blood samples were drawn from the antecubital region using a 21 gauge (19 mm) blood collection needle and blood collection tubes (Vacutainer, Franklin Lakes, NJ). Blood samples were given 30 minutes at room temperature (20-24º C) to clot and were subsequently centrifuged for 15 minutes at 3000 rpm and 4ºC. For storage, the serum was aliquoted into 2-mL polyethylene storage tubes and frozen at -80ºC until analysis.

Serum Hormone Measurements: T_3 concentration was analyzed as previously described (De Souza et al., 2007). A chemiluminescence immunoassay analyzer (Immulite, Diagnostic Products Corporation, Los Angeles, CA) was used to conduct competitive immunoassay. The T_3 assay had an analytical sensitivity of 0.54 nmol/L (35 ng/dL), the intraassay coefficient of variation was 13.2%, and the interassay coefficient of variation was 15.6%. Radioimmunoassay

(RIA; Linco Research, Inc., St. Charles, MO) was used to measure total serum ghrelin. The total ghrelin assay had a sensitivity of 29.7 pmol/L (100pg/mL), the intraassay coefficient of variation was 6.4%, and the interassay coefficient of variation was 16%.

Exercise Logs: Volunteers kept logs of their purposeful exercise on at least two separate seven-day occasions during the study. These logs provided a measurement of exercise volume (min/wk).

Exercise Status: Volunteers were required to participate in two or more hours per week of purposeful exercise as documented in the exercise logs during the study, and from exercise history review. We also utilized a VO_2 max of <40 ml/kg/min to reflect sedentary status and 40 ml/kg/min or greater to reflect exercising status consistent with other reports (Saltin & Astrand 1967).

Maximal Aerobic Capacity (VO_2 max): VO_2 max was measured during a progressive treadmill test to volitional exhaustion using indirect calorimetry on a single occasion during the study (De Souza et al. 2007a).

Eating Disorder Inventory-2 Questionnaire (EDI-2): The EDI-2 is a 91-item self-report measure of multidimensional symptom clusters associated with eating disorders (Garner et al., 1991). The EDI-2 includes three disordered eating subscales on attitudes and behaviors concerning eating, weight, and shape (DT, bulimia, body dissatisfaction), five personality subscales assessing organization constructs or psychological traits relevant to eating disorders (ineffectiveness, perfectionism, interpersonal distrust, interoceptive awareness, maturity fears), and three provisional subscales (asceticism, impulse regulation, social insecurity).

Statistical Analysis: All data sets were tested for non-normality, homogeneity of variance, and outliers before statistical hypothesis tests were performed. Data were expressed as mean ± SD. Clinical characteristics (i.e., age, height, body mass, BMI, body composition, VO_2 max, exercise volume, age of menarche, gynecological age) and data for all psychometric, energetic, and reproductive characteristics were compared among the groups using an Independent Student's *t*-test. Additionally, Pearson correlations were performed between anthropometric, energetic, metabolic hormone, and psychological characteristics. All data were analyzed using SPSS for Windows (version 19.0, Chicago, IL) statistical software package.

Chapter 4

Results

Clinical Characteristics: The clinical characteristics of the participants are presented in **Table 1**.

Age and gynecological age were significantly higher ($p<0.01$) in the Normal CR + Normal Disinhibition group compared with the other groups. Height, body mass, BMI, and age of menarche were similar ($p>0.05$) between groups. Post-hoc analyses revealed that women with high CR and high disinhibition have a significantly higher BMI ($p<0.05$) than the other groups. Fat mass was significantly higher ($p<0.05$) in the High CR + High Disinhibition group. All of the women in this study were considered to be of "above average" physical fitness by ACSM classification (ACSM, 2006). They exhibited a total activity volume greater than or equal to 120 min/week and a VO_2 max of ~46mL/kg/min.

Psychometric Parameters: The psychometric profile data of the participants are presented in **Table 2**. By study design, CR scores were higher ($p<0.001$) in the high CR groups compared to the normal control group. As well, disinhibition scores were higher ($p<0.001$) in the high disinhibition groups vs. the normal control group. Hunger scores were significantly higher ($p<0.05$) in the High CR + High Disinhibition group than in the other groups. The scores for drive for thinness on the EDI-2 subscales were significantly lower ($p<0.01$) in the Normal CR + Normal Disinhibition group than in the High CR + Normal Disinhibition or the High CR + High Disinhibition groups. Scores for bulimia on the EDI-2 were significantly higher ($p<0.05$) in the women with high CR and high disinhibition than the women in the other groups. Women in the Normal CR + Normal Disinhibition group had significantly lower ($p<0.05$) body dissatisfaction

Table 1. Clinical characteristics of the exercising women grouped by the dietary cognitive restraint and disinhibition scores.

	Normal CR + Normal Disinhib (n=38)	High CR + High Disinhib (n=20)	High CR + Normal Disinhib (n=37)
Demographic/Anthropometric Characteristics			
Age (yrs)	24.8±4.4[a]	21.4±3.6	21.6±2.8
Height (cm)	164.6±6.9	164.3±3.5	166.4±5.1
Body Mass (kg)	56.8±6.4	59.7±5.1[b]	57.4±5.1
BMI (kg/m^2)	20.9±1.9	22.1±1.5	20.7±1.9
Reproductive Characteristics			
Age of Menarche (yr)	12.8±1.6	13.8±1.7	12.9±1.7
Gynecological Age (yr)	12.0 ±4.5[a]	7.7±4.2	8.6±3.5
Body Composition Characteristics			
Body Fat (%)	24.4±5.4	27.2±4.6	23.8±5.3
Fat Mass (kg)	13.8±3.9	16.3±3.6[b]	13.6±3.7
Lean Body Mass (kg)	40.5±4.2	41.2±4.2	41.4±3.6
Exercise Status			
Total Activity Volume (min/wk)	329±225	232±124	432±181[c]
VO_2 max (ml/kg/min)	47.4±7.0	46.6±8.0	45.2±6.6

Values are mean ± SD.

BMI = Body Mass Index.

CR = Dietary Cognitive Restraint.

Disinhib = Disinhibition

High dietary cognitive restraint score (CR≥11).

High disinhibition score (Disinhib≥8).

[a] Normal CR + Normal Disinhib vs. High CR + Normal Disinhib and High CR + High Disinhib; ANOVA with LSD post-hoc ($p<0.05$)

[b] High CR + High Disinhib vs. High CR + Normal Disinhib and Normal CR + Normal Disinhib; ANOVA with LSD post-hoc ($p<0.05$)

[c] High CR + Normal Disinhib vs. High CR + High Disinhib and Normal CR + Normal Disinhib; ANOVA with LSD post-hoc ($p<0.05$)

Table 2. Psychometric data of the exercising women grouped by the dietary cognitive restraint and disinhibition scores.

	Normal CR + Normal Disinhib (n=38)	High CR + High Disinhib (n=20)	High CR + Normal Disinhib (n=37)
EDI-2			
Drive for Thinness	0.9±1.6[a]	5.5±5.0	4.0±4.7
Bulimia	0.1±1.6	1.1±1.5[b]	0.3±1.2
Body Dissatisfaction	3.3±5.1[a]	8.1±5.5	6.0±5.4
Ineffectiveness	0.5±1.2	1.7±2.7	1.8±3.4[c]
Perfectionism	5.8±3.4	6.3±3.6	6.7±4.1
Interpersonal Distrust	1.0±1.3[a]	2.8±4.0	3.0±3.8
Interoceptive Awareness	0.7±1.7	3.1±4.8[d]	1.8±3.1
Maturity Fears	2.0±2.4	3.0±3.1	2.7±2.7
Asceticism	2.6±1.5	3.9±2.2[b]	2.7±1.9
Social Insecurity	1.2±1.5	2.5±3.1	2.4±2.8
Impulse Regulation	0.7±1.8	1.6±2.9	1.1±2.1[c]
TFEQ			
Disinhibition	3.6±2.0	9.6±1.7[b]	4.1±1.5
Cognitive Restraint	5.9±2.7[a]	13.4±2.6	14.8±2.8
Hunger	4.9±2.7	7.1±2.6[b]	5.0±2.2

Values are mean ± SD.

CR = Dietary Cognitive Restraint.

Disinhib = Disinhibition

EDI-2 = Eating Disorder Inventory-2.

TFEQ = Three Factor Eating Questionnaire.

High dietary cognitive restraint score (CR≥11).

High disinhibition score (Disinhib≥8).

[a] Normal CR + Normal Disinhib vs. High CR + Normal Disinhib and High CR + High Disinhib; ANOVA with LSD post-hoc ($p<0.05$)

[b] High CR + High Disinhib vs. Normal CR + Normal Disinhib and High CR + Normal Disinhib; ANOVA with LSD post-hoc ($p<0.05$)

[c] High CR + Normal Disinhib vs. Normal CR + Normal Disinhib; ANOVA with LSD post-hoc ($p<0.05$)

[d] High CR + High Disinhib vs. Normal CR + Normal Disinhib; ANOVA with LSD post-hoc ($p<0.05$)

scores than women in the other groups. Scores for ineffectiveness were significantly lower ($p<0.05$) in the Normal CR + Normal Disinhibition group than in the High DR + Normal Disinhibition group. Women with normal levels of CR and disinhibition had significantly lower scores ($p<0.05$) for interpersonal distrust than women in the High CR + Normal Disinhibition and High CR + High Disinhibition groups. The scores for interoceptive awareness were significantly lower ($p<0.01$) in the Normal CR + Normal Disinhibition group than the High CR + High Disinhibition group. The High CR + High Disinhibition group exhibited scores for asceticism that were significantly higher ($p<0.05$) than the other groups. Women in the High CR + High Disinhibition group had social insecurity scores which were significantly higher ($p<0.05$) than the Normal CR + Normal Disinhibition group.

Energy Availability: Energy availability, energy intake and exercise energy expenditure are presented in **Figure 1**. Energy availability was significantly lower ($p<0.01$) in the High CR + Normal Disinhibition group in comparison to the Normal CR + Normal Disinhibition group. There were no statistically significant differences between the women with high CR and high disinhibition and with normal CR and normal disinhibition ($p>0.05$). Energy intake was significantly higher ($p<0.05$) in the Normal CR + Normal Disinhibition group than the other two groups. There were no significant differences in Exercise Energy Expenditure between the groups.

Energy Status and Metabolic Hormones: Energy status and metabolic hormone data are presented in **Table 3**. There were no significant results for any of the energetic and metabolic variables.

Correlations: Pearson correlation analyses between anthropometric variables, energetic variables, metabolic hormones, and eating behavior characteristics in exercising women are presented in **Table 4**. CR score was inversely related to the ratio of REE/pREE ($r=-0.199$, p=0.039) in exercising women. Disinhibition score was positively related to body mass (r=0.252, p=0.008) in our participants.

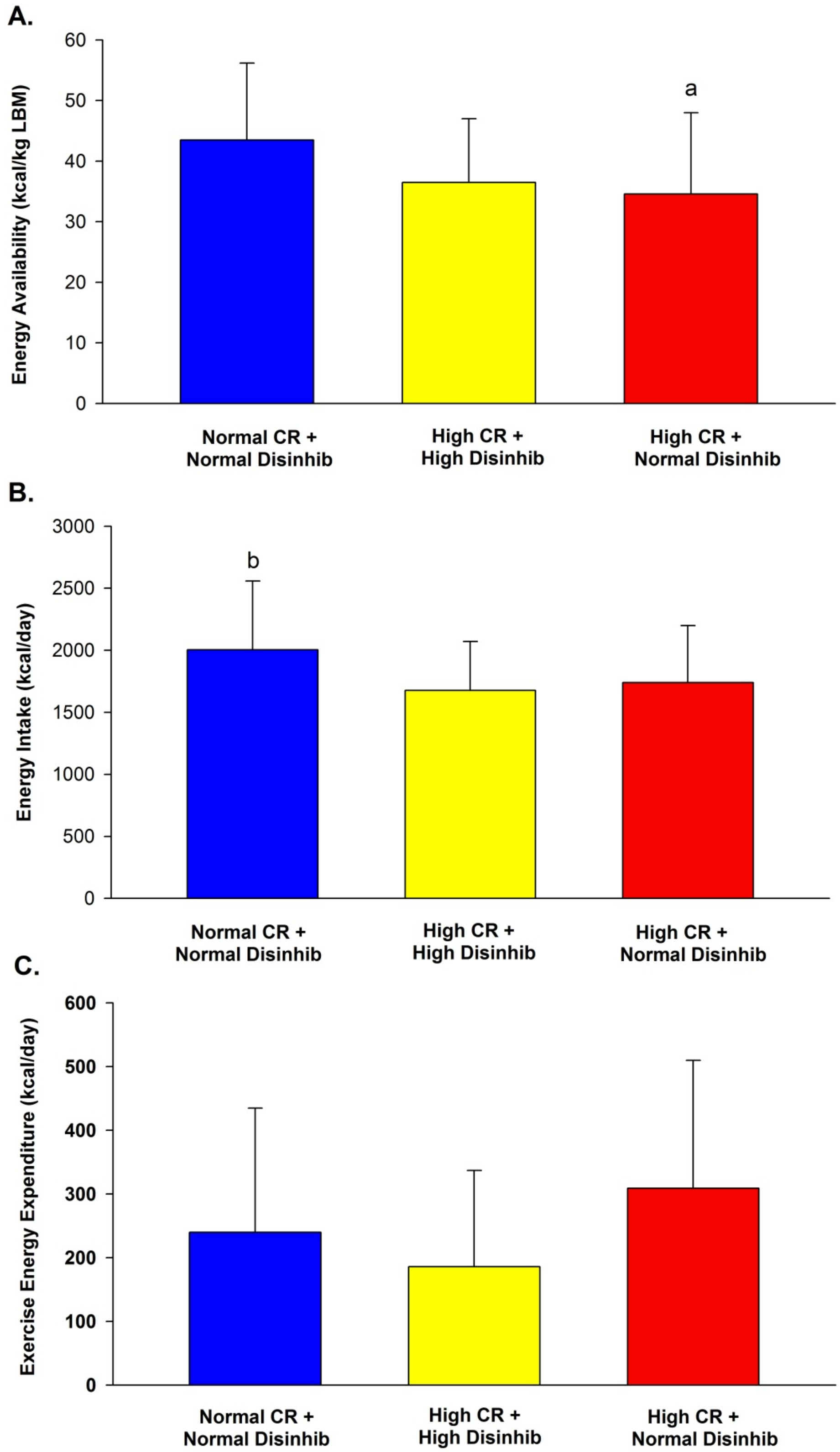

Figure 2. Energy availability parameters (energy availability, energy intake, exercise energy expenditure, and lean body mass) in exercising women categorized by CR and disinhibition status

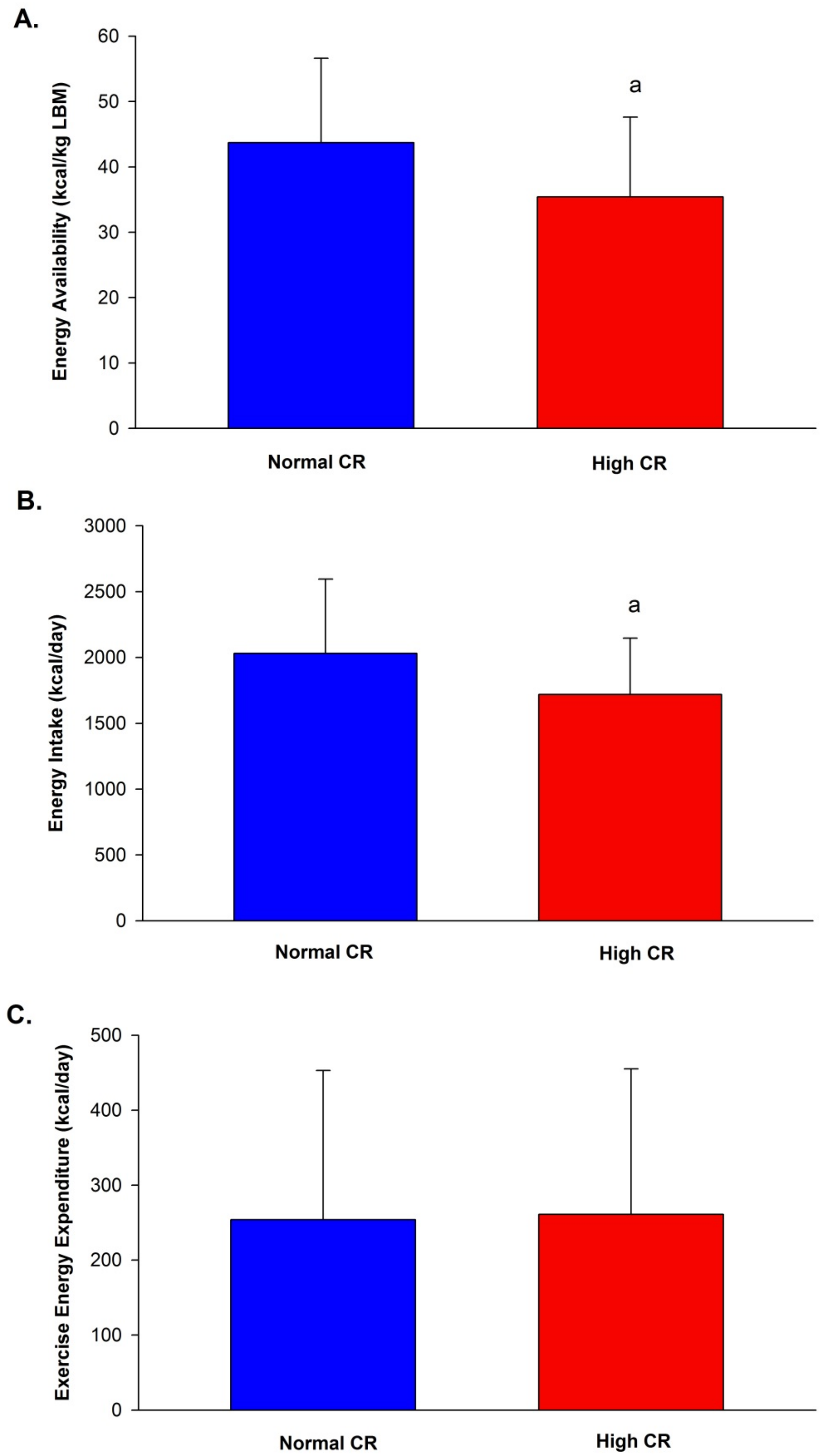

Figure 3. Energy availability in exercising women categorized by CR status

Table 3. Energetic and metabolic profiles of the exercising women grouped by the dietary cognitive restraint and disinhibition scores.

	Normal CR + Normal Disinhib (n=38)	High CR + High Disinhib (n=20)	High CR + Normal Disinhib (n=37)
Energetic Characteristics			
REE (kcal/day)	1246±134	1225±111	1250±130
Adjusted REE (kcal/d/kg LBM)	30.9±2.6	30.0±3.0	30.3±3.2
REE/pREE	0.90±0.09	0.86±0.08	0.89±0.09
Metabolic Hormones			
T_3 (ng/dl)	91.6±20.2	93.8±24.2	90.8±23.2
Ghrelin (pg/ml)	1289.8±428.3	1194.8±385.3	1427.8±423.2

Values are mean ± SD.
CR = Dietary Cognitive Restraint.
Disinhib = Disinhibition

Table 4. Pearson correlations between anthropometric variables, energetic variables, metabolic hormones, and eating behavior characteristics in exercising women.

	Cognitive Restraint Score		**Disinhibition Score**	
	R-value	p-value	R-value	p-value
Anthropometric Variables				
Body mass (kg)	0.044	0.685	0.238	0.008**
Body Mass Index (kg/m2)	0.067	0.539	0.192	0.077
Energy Availability Variables				
Energy Availability (kcal/kg LBM)	-0.351	0.001**	-0.068	0.532
Energy Intake (kcal/day)	-0.379	<0.001**	-0.098	0.369
Exercise Energy Expenditure (kcal/day)	-0.047	0.666	-0.142	0.192
Lean Body Mass (kg)	-0.033	0.762	0.131	0.230
Energetic Variables				
REE (kcal/day)	-0.153	0.160	0.017	0.877
Adjusted REE (kcal/day/kg LBM)	-0.135	0.214	-0.114	0.297
REE/pREE	-0.255	0.018*	-0.179	0.099
Metabolic Hormones				
T_3 (ng/dl)	-0.053	0.629	0.002	0.985
Ghrelin (pg/ml)	0.059	0.589	-0.046	0.672

*Significant correlations (p<0.05)
**Significant correlations (p<0.01)

Chapter 5

Discussion

Our findings demonstrate that a high CR alone is associated with lower EA, primarily via reductions in EI, in exercising women, independent of disinhibition. Consistent with our hypothesis, women with high CR and normal disinhibition exhibited lower EA than those with normal CR and disinhibition. However, there were no significant differences in EA between the women with high CR and normal disinhibition compared to the women with high CR and high disinhibition. Therefore, we can suggest that disinhibition score does not further discriminate these women by EA. When categorized solely by CR score, the high CR group had significantly lower EA in comparison to the normal CR group and thus, we can suggest that a high CR may be a key factor in reducing EA in exercising women and the CR subscale alone may represent a better psychometric indicator of EA in exercising women.

In our study, the association between CR and EA was primarily driven by the reduction in EI in women with high CR. Lower energy intake related to a high CR is well documented (Reed et al., 2011; Laessle et al., 1989; Klesges et al., 2002; Mulvihill et al., 2002), but there have been few investigators that explored the link between CR and EA. A high CR could be the origin of a low EA because high CR promotes energy restriction in order to maintain or achieve an ideal body weight. Women with a high CR constantly monitor their energy intake to meet a certain caloric cutoff, which they deem appropriate, and research has demonstrated that women with high CR do consume fewer kilocalories than women with normal CR (Mulvihill et al., 2002; Klesges et al., 1992; Laessle et al., 1989). CR also impacts the food choices that highly restrained individuals make. Research has demonstrated that women with a high level of restraint consumed a smaller portion of their diet in carbohydrates and fat and a larger portion as protein (Lluch et al., 2000; Laessle et al., 1989; de Castro, 1995). They are also more likely to select foods which they consider low-calorie and healthy (Laessle et al., 1989; de Castro, 1995; Tuschl et al., 1990b) and avoid foods which they consider energy-dense or unhealthy (Laessle et al., 1989; de Castro, 1995; French et al., 1994). Rideout et al. (2004) suggested that restrained eaters pay more attention to the caloric composition of foods rather than its actual nutrition value. Our findings demonstrated that women with high CR consumed significantly fewer kilocalories per day than women with normal CR. In a population of exercising women, Reed et al. (2011) demonstrated an inverse correlation between CR score and energy intake, which we also demonstrated in our study. There was no significant difference, however, in energy intake between the women with high CR and high disinhibition compared to the women with high CR women and low disinhibition. This was surprising because we hypothesized that women with high CR and high disinhibition would have a higher energy intake than women with high CR and normal disinhibition. This result may indicate that CR is a more robust subscale than disinhibition in identifying lower EA and EI.

The relationship between CR, exercise energy expenditure, and energy intake is complex and not well understood. Hill et al. (1995) proposed a model to explain the effects of cognitive restraint and disinhibition on energy compensation after exercise energy expenditure. Unrestrained eaters respond to physiological cues of hunger and satiety in their energy consumption. After exercise, these individuals would be sensitive to physiological hunger cues, and theoretically, consume an amount of food restoring energy balance. On the other hand, restrained eaters impose cognitive control on their intake of food and would be less likely to respond to the physiological cues of hunger created by the energy demands of exercise (Hill et al., 1995). These individuals would be less likely to compensate for the energy used during exercise, and therefore, be more likely to develop an energy deficiency. The effect of high disinhibition on energy intake in exercising women is unclear. Hill et al. (1995) describes an individual with high disinhibition as overweight and an unsuccessful dieter, who in successful periods may be able to restrain their eating by ignoring hunger cues but in unsuccessful periods would be susceptible to disinhibited overeating. This description of the disinhibition phenotype, however, is not consistent with the exercising women in our study population; all of the women in our study were of a healthy weight, even those who scored high on the disinhibition subscale.

In exercising women, it is important to consider how cognitive restraint affects energy intake after exercise energy expenditure. Much research has been conducted to examine the acute effect of exercise on food intake, or how exercise immediately affects the amount of food consumed in the short term. Lluch and colleagues (1998) demonstrated that in restrained women, exercise energy expenditure did not have a significant effect on the amount of energy intake, which was consumed at a subsequent meal or throughout the remainder of the day. The researchers found that exercise decreased relative energy intake by 43% when controlling for the exercise energy expenditure, and this meant that women with high CR failed to compensate for the energy expended in physical activity. Research on the role of disinhibition on the energy intake response following exercise has shown mixed results. Both Keim et al. (1996) and Visona and George (2002) demonstrated that women with high disinhibition increased their short-term energy intake in response to exercise. On the other hand Bryant et al. (2005) demonstrated that in women with high disinhibition, exercise actually had a positive effect on the regulation of food intake, motivation to eat, and overall mood. The differences in these results can likely be contributed to the use of obese versus lean participants because it seems that disinhibition can be influenced by weight status. Additionally, these studies solely exhibit the acute effect of CR and disinhibition on energy intake following exercise, but more research needs to be completed examining the chronic effects on dietary compensation post-exercise. Such investigation would be useful in determining whether these decreases or increases in energy intake accumulate in the long term in women with high CR vs. those with normal CR.

Whether women demonstrate successful or unsuccessful restraint may depend on their disinhibition score because women with a high level of disinhibition would be more likely to reverse inhibition. Women who are unsuccessful at restraining their energy intake would likely have a higher BMI, percentage of body fat, and body weight than women who are successful restrainers. The results of our study demonstrated that women with both high disinhibition and CR had a significantly greater amount of fat mass and a higher BMI than women in the other two groups. They also had a higher body fat percentage, which exhibited a trend toward statistical significance. All of the women in this study were weight stable, and therefore, body fat, BMI, and body fat percentage may represent chronic adaptations to higher energy availability. Other studies have also found similar associations between disinhibition and these measures of body composition (Lawson et al., 1995; Dykes et al., 2004; Bellisle et al., 2004). In terms of the acute adaptations to low EA in exercising women, typically we would observe suppressed REE, increased concentrations of ghrelin, and decreased concentrations of leptin. Another marker that can be used to determine energy status is the ratio of measured REE to predicted REE calculated by the Harris-Benedict equation (Harris and Benedict, 1918). Research has shown that in clinical models of starvation, the REE/pREE ratio is typically between 0.60-0.80, indicating that in periods of low energy availability, REE is suppressed to 60-80% of the expected REE (Marra et al., 2002; Melchior et al., 1989; Polito et al., 2000). As previously published by our lab, energy deficiency is operationally defined as a REE/pREE ratio of <0.90 (De Souza et al., 2007). Reed et al. (2011) demonstrated that women experiencing exercise-associated menstrual cycle disturbances had a significantly lower energy intake, resting energy expenditure, and energy availability than women who had regular menstrual cycles. The women with menstrual disturbances also exhibited significantly higher drive for thinness and CR scores than the ovulatory controls. Vescovi et al. (2008) demonstrated that women in the highest quartile of CR scores had significantly lower REE and REE/pREE ratios than women in the lower quartiles, and the average value for REE/pREE in the highest quartile was less than 0.90, while the average of the other three quartiles was above 0.90. Platte and colleagues (1996) found that individuals with high CR did exhibit lower REE than women with normal CR. This study also introduced a novel view of the relationship between restrained eating and RMR; it suggests that a lower REE may not only be a consequence of restrained eating but a cause of this type of eating behavior. In women who have a genetic predisposition for a lower REE, restrained eating may be a behavioral adaptation, which has developed in order to prevent weight gain. Our findings demonstrated that CR was associated with REE/pREE, but there was no other evidence of metabolic adaptations to an energy deficiency when the women were categorized by CR and disinhibition score.

The groups with high CR independent of disinhibition did meet our operational definition of energy deficiency, having a REE/pREE<0.90, but it is possible that our population was not representative of a truly restrictive or subclinical disordered eating population. We would argue that in women with high CR who successfully restrict energy intake, they would also demonstrate a high drive for thinness score (greater than or equal to 7) and a high perfectionism score (greater than or equal to 9) (Gibbs et al., 2011; De Souza et al., 2007). These cut-offs have been well-documented in exercising women who demonstrate subclinical disordered eating and evidence of an energy deficiency (Gibbs et al., 2011; De Souza et al., 2007), but the mean scores in our study groups were not indicative of this restrictive eating behavior phenotype. In 2007, De Souza et al. demonstrated that a high CR coupled with a high drive for thinness was associated with energy deficiency in the same population examined by this current study. Although this was the case, the high CR and normal disinhibition group was not significantly different than the high CR and high disinhibition group with respect to indices of energy deficiency. The women in our study did not exhibit a high drive for thinness, so this could be one reason for the lack of association between high CR and metabolic indicators of energy deficiency.

Women with high levels of CR and high disinhibition are thought to have eating behaviors that are reflective of a bingeing and purging pattern. Our findings revealed that the women with high CR and disinhibition scores also demonstrated significantly higher scores for bulimia than the other groups, and significantly higher body dissatisfaction and drive for thinness scores than women with normal levels of CR and disinhibition. These factors may be reflective of a history of weight-cycling despite currently being weight stable. Additionally, the women with high CR and high disinhibition demonstrated the lowest energy intake in our study and thus, may be in a more restrictive phase of this cycle in order to maintain or lose body weight. If we had included a fourth group of women with normal CR and high disinhibition in our study, we would have predicted that these women would have more episodes of overeating and therefore even higher BMI, body weight, and EA. Lawson et al. (1995) conducted a study to examine the relationship between CR, disinhibition, adiposity, eating disturbances, and energy expenditure. They demonstrated that women with low CR and high disinhibition were generally obese, and women with high disinhibition were more likely to exhibit episodic overeating. Although there were no significant differences in REE between the women, high disinhibition was significantly related with adiposity and eating disturbances (Lawson et al., 1995). We would not expect to observe a large sample of women from our population with low CR and high disinhibition because this particular eating phenotype is not very prevalent in populations of normal-weight, exercise women.

A limitation of this study was the collection of energy intake and exercise energy expenditure data through self-reported logs. Previous studies have demonstrated that self-reported food records are prone to inaccuracies in the form of under-reporting (Martin et al., 1996; Sawaya et al. 1996). Rennie et al. (2006) demonstrated that under-reporting was more common in women with high CR than in those with low CR. We took special precautions to prevent reporting inaccuracies by having a registered dietitian train each of the subjects on food recording techniques. This same limitation applies to quantifying exercise energy expenditure as well. Since the subjects in our study were free-living women who self-reported their volumes of purposeful exercise, it is difficult to ensure accuracies in the recorded exercise information. Discrepancies in either energy intake or expenditure could decrease the accuracy of our EA results. Another limitation to this study is that we used CR and disinhibition as dichotomous variables, classifying women as either high or normal, whereas these variables may actually exist on a spectrum or demonstrate more significant differences comparing the extreme presentations (high vs. low) and excluding the women in between.

In conclusion, these findings suggest that an association exists between CR score and EA in exercising women independent of the effects of disinhibition. This was only a cross sectional study, so further research needs to be conducted to examine the relationship between CR, disinhibition, and EA in a more long-term manner. An investigation could be done that involves training sedentary women in order to examine the effects of chronic exercise training on energy availability in women with high CR compared to those with normal CR. It could examine the energy intake of women over the 24-hour period after a bout of exercise or furthermore, measure EA in a more controlled, laboratory setting. This type of study ensures a higher degree of accuracy in the collection of energy intake and exercise energy expenditure data, the two major determinants of EA. It would also be beneficial to examine women at the extremes, both high and low, of CR and disinhibition scores or look across the spectrum of restraint in a more controlled manner to gain a better understanding of the relationship between CR, disinhibition, and EA. Overall, the CR subscale alone may be a better psychometric indicator of EA in exercising women than the combination of CR and disinhibition.

Chapter 6

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Appendix I

Three Factor Eating Questionnaire

(Note: Items dealing with Disinhibition are highlighted in blue, and items dealing with Cognitive Restraint are highlighted in red.)

Part I

Directions: Read each statement carefully and circle a "T" if it is "true" for you or a "F" is it is "false" directly onto the survey.

T F 1. When I smell a freshly baked pizza, I find it very difficult to keep from eating, even if I have just finished a meal.

T F 2. I usually eat too much at social occasions, like parties and picnics.

T F 3. I am usually so hungry that I eat more than three times a day.

T F 4. When I have eaten my quota of calories/fat, I am usually good about not eating any more.

T F 5. Dieting is so hard for me because I just get too hungry.

T F 6. I deliberately take small helpings as a means of controlling my weight.

T F 7. Sometimes things just taste so good that I keep on eating even when I am no longer hungry.

T F 8. Since I am often hungry, I sometimes wish that while I was eating, an expert would tell me that I have had enough or that I can have something more to eat.

T F 9. When I feel anxious, I find myself eating.

T F 10. Life is too short to worry about dieting.

T F 11. Since my weight goes up and down, I have gone on reducing diets more than once.

T F 12. I often feel so hungry that I just have to eat something.

T F 13. When I am with someone who is overeating, I usually overeat too.

T F 14. I have a pretty good idea of the number of calories/grams of fat in common foods.

T F 15. Sometimes when I start eating, I just can't seem to stop.

T F 16. It is not difficult for me to leave something on my plate.

T F 17. At certain times of the day, I get hungry because I have gotten used to eating then.

T F 18. While on a diet, if I eat food that is not allowed, I consciously eat less for a period of time to make up for it.

T F 19. Being with someone who is eating often makes me hungry enough to eat also.

T F 20. When I feel blue, I often overeat.

T F 21. I enjoy eating too much to spoil it by counting calories, counting grams of fat, or watching my weight.

T F 22. When I see a real delicacy, I often get so hungry that I have to eat right away.

T F 23. I often stop eating when I am not really full as a conscious means of limiting the amount I eat.

T F 24. I get so hungry that my stomach often seems like a bottomless pit.

T F 25. My weight has hardly changed at all in the last ten years.

T F 26. I am always hungry so it is hard for me to stop eating before I finish the food on my plate.

T F 27. When I feel lonely, I console myself by eating.

T F 28. I consciously hold back at meals in order not to gain weight.

T F 29. I sometimes eat very late in the evening or at night.

T F 30. I eat anything I want, any time I want.

T F 31. Without even thinking about it, I take a long time to eat.

T F 32. I count calories/grams of fat as a conscious means of controlling my weight.

T F 33. I do not eat some foods because they make me fat.

T F 34. I am always hungry enough to eat at any time.

T F 35. I pay a great deal of attention to changes in my figure.

T F 36. While on a diet, if I eat a food that is not allowed, I often then splurge and eat other high calorie foods.

Part II

Directions: Please answer the following questions by circling the number above the response that is appropriate to you directly onto the survey.

37. How often are you dieting in a conscious effort to control your weight?

1	2	3	4
rarely	sometimes	usually	always

38. Would a weight fluctuation of 5 lbs affect the way you live your life?

1	2	3	4
not at all	slightly	moderately	very much

39. How often do you feel hungry?

1	2	3	4
only at mealtimes	sometimes between meals	often between meals	almost always

40. Do your feelings of guilt about overeating help you to control your food intake?

1	2	3	4
never	rarely	often	always

41. How difficult would it be for you to stop eating halfway through dinner and not eat for the next four hours?

1	2	3	4
easy	slightly difficult	moderately difficult	very difficult

42. How conscious are you of what you are eating?

1	2	3	4
not at all	slightly	moderately	extremely

43. How frequently do you avoid 'stocking up' on tempting foods?

1	2	3	4
almost never	seldom	usually	almost always

44. How likely are you to shop for low calorie foods?

1	2	3	4
unlikely	slightly unlikely	moderately likely	very likely

45. Do you eat sensibly in front of others and splurge alone?

1	2	3	4
never	rarely	often	always

46. How likely are you to consciously eat slowly in order to cut down on how much you eat?

1	2	3	4
unlikely	slightly likely	moderately likely	very likely

47. How frequently do you skip desert because you are no longer hungry?

1	2	3	4
almost never	seldom	at least once a week	almost every day

48. How likely are you to consciously eat less than you want?

1	2	3	4
unlikely	slightly likely	moderately likely	very likely

49. Do you go on eating binges though you are not hungry?

1	2	3	4
never	rarely	sometimes	at least once a week

50. On a scale of 1 to 6, where 1 means no restraint in eating (eat whatever you want, whenever you want it) and 6 means total restraint (constantly limiting food intake and never "giving in"), what number would you give yourself?

1-eat whatever you want, whenever you want it
2-usually eat whatever you want, whenever you want it
3-often eat whatever you want, whenever you want it
4-often limit food intake, but often "give in"
5-usually limit food intake, rarely "give in"
6-constantly limiting food intake, never "giving in"

51. To what extent does this statement describe your eating behavior? 'I start dieting in the morning, but because of any number of things that happen during the day, by evening I have given up and eat what I want, promising myself to start dieting again tomorrow.'

1	2	3	4
not like me	little like me	pretty good description of me	perfectly describes me

52. I presently think of myself as being:

___underweight
___at a healthy weight
___mildly overweight/over fat
___moderately overweight/overfat
___very overweight/over fat
___people tell me I'm too thin
___people tell me I'm too fat
___I see myself as being fat
___the coach told me to lose weight

53. Have you ever purposely dieted to lose weight?

_______Yes (please answer #54)
_______No (skip to #55)

54. If you answered yes to #53, what method(s) have you tried? (check all that apply)

_______ate low fat foods
_______drugs (please specify)
_______other, please
specify:____

55. Have you ever been diagnosed with an eating disorder?

_______Yes (please answer #56)
_______No (skip to #59)

56. If you answered yes to #55, please check the correct diagnosis:

_______Anorexia
_______Bulimia
_______Obsessive/Compulsive binge eating
_______Bulimarexia
_______Other, please
list:____

57. Have you been hospitalized for an eating disorder?

_______Yes (please answer #58)
_______No (skip to #59)

58. If you answered yes to #57, please specify date(s)
hospitalized:_________________________________

59. Have you ever received professional counseling for eating problems?

_______Yes (please answer #60)
_______No (skip to #62)

60. If you answered yes to #59, please specify length of counseling:

______________Began
______________Ended

61. Are you currently in counseling for food related problems?

_______Yes
_______No

62. Do you drink fluids after you exercise?

_______Yes
_______No

63. In your opinion, do you "over" exercise?

_______Yes
_______No

64. In your opinion, are you experiencing any problems (other than a diagnosed injury) that could be related to your exercise program?

_______Yes (please answer #65)
_______No

65. If you answered yes to #64, please explain:_______________________________________

ACADEMIC VITA

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Permanent Address
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Indiana, PA 15701
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EDUCATION

The Pennsylvania State University **University Park, PA**
Schreyer Honors Scholar Graduation: May 2012
B.S. Nutritional Sciences, Applied Sciences Option
Kinesiology Minor

EXPERIENCE

Laboratory Experience

Women's Health and Exercise Laboratory at The Pennsylvania State University 2011-Present
University Park, PA

- Assist with interdisciplinary research studying the relationship between energy balance, reproductive function, bone health, and exercise performance in exercising women
- Help perform measures of urinary steroids and gonadotropins, resting metabolic rate, VO2 Max, body composition, and reproductive hormone levels
- Conduct research for an honors thesis on cognitive restraint and disinhibition in female athletes

Professional Experience

Eagle Lake Camp Kitchen Director Summer 2010
Woodland Park, CO

- Planned and executed meal service for 500 people, 2 meals a day, 6 days a week
- Supervised food preparation, safety, sanitation, inventory, and ordering
- Developed leadership and management skills while directing a crew of high school students

Green Mountain Summer Training Program Assistant Cook Summer 2011
Burlington, VT

- Planned weekly menus and purchased food for the entire program
- Assisted in daily meal preparation

Leadership Experience

Penn State Navigators Secretary 2011-Present

- Help plan and organize large group meetings, events, and trips for the entire organization
- Create promotional materials and help with recruitment of new members

Penn State Navigators Bible Study Leader/Mentor 2010-Present

- Lead a group of 10 sophomore women in a weekly Bible Study
- Meet weekly with several sophomore women in order to guide them through their college experience

Green Mountain Summer Training Program Team Leader Summer 2011

- Led a team of five young women and mentored them each individually
- Planned group meetings and weekend outings for the entire program

EXTRACURRICULAR ACTIVITIES

Penn State Navigators
The Daily Collegian Graphic Artist
Student Nutrition Association
Penn State Campus Band
Intramural Volleyball and Soccer

HONORS

Dean's List 8/8 semesters
The John E. Smith Outstanding Senior in Nutrition Award
Phi Kappa Phi Honor Society
Kappa Omicron Nu Honor Society
The Daily Collegian Graphics Candidate of the Semester
Robeson Memorial Scholarship
PSECU Scholarship Finalist

COMMUNITY SERVICE

Penn State IFC/Panhellenic Dance Marathon
New England Disaster Relief after Vermont Flooding
Kids Alive in Burlington, Vermont
Spring Break Service Projects:

- Green Light New Orleans in New Orleans, Louisiana
- Rescue Atlanta in Atlanta, Georgia
- Neighborhood revitalization in Jacksonville, Florida
- Barefoot Republic Camp in Fountain Run, Kentucky