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IMPACT OF RESISTANCE TRAINING ON BONE MINERAL DENSITYAND PERFORMANCE IN COMPETITIVE FEMALE GYMNASTS

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BY

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ABSTRACT

This study investigated the effects of a ten week resistance training intervention on bone mineral density and performance measures in competitive female adolescent gymnasts. Previous research indicates resistance training improves performance and reduces injury risk. Resistance training as a mode to reduce injury risk may be of primary importance in sports with history of high injury rates but low participation in resistance training, such as gymnastics. Sixteen female adolescent gymnasts between the ages of 12-20 competing at Junior Olympic levels 7-10 were recruited. Participants were divided into resistance training (N = 10 age; 13.5±1.00 years, height; 155.19±8.38 cm, weight; 51.58±9.63 kg) or gymnastics training (N = 6 age; 15.25±2.25 years, height; 149.23±11.91 cm, weight; 46.52±10.22 kg) groups. The resistance training group participated in a high impact resistance training program twice a week on non-consecutive days for ten weeks while the gymnastics training group continued regular participation in gymnastics practice. Resistance training resulted in significant improvements in bone mineral density, power and jump height, as well as maximal strength ($p \leq 0.05$). Conclusion: Full body, high impact resistance training performed on non-consecutive days, following non-linear periodization for 1.5 to 2 hours per week for ten weeks is sufficient to obtain bone mineral density and performance improvements in competitive female adolescent gymnasts.

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This thesis is written to comply with the University of Rhode Island graduate school Manuscript Thesis Format. This thesis contains one manuscript: *Impact of Resistance Training on Bone Mineral Density, Tendon Thickness, and Performance in Competitive Female Gymnasts.* This manuscript has been written in a form suitable for publication in *Journal of Strength & Conditioning Research*.

CHAPTER 1

INTRODUCTION

The number of athletes competing in gymnastics in the United States has risen from 7,000 in the 1960s to over 90,000 currently (USA Gymnastics). Females account for almost 76% of gymnastics participants in the United States and 80% of gymnastics participants are under 18 years of age (USA Gymnastics).

The rate of injury in women's gymnastics is higher when compared to other sports (Colvin et al. 2010, Singh et al. 2008). Participation is associated with an increased risk of stress fractures and produces the highest number of injuries requiring surgeries (Colvin et al. 2010). Tendon and ligament sprains and stress fractures are the most prominent injuries (Singh et al. 2008).

Despite this elevated risk of bone and connective tissue injury, data suggests that female gymnasts average greater bone density then their peers (Burt et al. 2012, Helge et al. 2002, Maimoun et al. 2011, Morel et al. 2001, Nichols et al. 2007). A meta-analysis done in 2012 by Lauren Burt reported that young female gymnasts age 6-12 years old show greater bone density then non-gymnasts (Burt et al. 2012). According to a study in the Journal of Bone and Mineral Metabolism, gymnasts age 11-16 years have greater bone strength index then non active females (Greene et al. 2012). However, research is conflicting. Artistic gymnasts training more than fifteen hours per week report greater percentages of amenorrhea and inadequate dietary intake (Ducher et al. 2009, Myer et al. 2011, Soric et al. 2008) which may result in compromised bone mineral density (Colvin et al. 2010, Ducher et al. 2009, Warren 1999). Increased incidence of traumatic and stress fracture with compromised bone mineral density (BMD) has been documented (Colvin et al. 2010, Ducher et al. 2009, Warren 1999). Further evidence shows greater risk of injury during peak bone growth in adolescence (Bailey et al. 1989, Colvin et al. 2010) and greater general risk of injury due to the nature of the sport (Colvin et al. 2010, Singh et al. 2008).

The National Strength and Conditioning Association (NSCA) defines resistance training as a specialized method of conditioning, which involves the progressive use of a wide range of resistive loads and a variety of training modalities designed to enhance health, fitness, and sports performance (Faigenbaum et al. 2009). The NSCA's position stand on youth and adolescent resistance training states that regular participation in resistance training can strengthen bone, improve motor performance skills, and increase resistance to sport related injuries (Faigenbaum et al. 2009). A review on strategies to prevent injury in adolescent sport published in 2007 by the British Journal of Sports Medicine cited strength training as a significant method for reduction of sports injury (Abernethy et al. 2007). In 2006 a Meta-analysis done by Hewett et al. found that research designs using strength training were the most effective at preventing ACL injury to female athletes (Hewett et al. 2006).

Due to the competitive nature and intense training often associated with participation in gymnastics, improving technical skill, strength, speed and power are of upmost importance while concomitantly reducing risks for injury. Research suggests that resistance training can decrease injury risk through improvement of bone mineral density as well as positively affect performance (Kraemer 2009, Nichols et al.

2007). The impact of resistance training on increasing bone mineral density is well documented. Specifically, research published by David Nichols in 2001 demonstrates increased BMD following resistance training in adolescent females (Nichols et al. 2001). Numerous publications have demonstrated that regular participation in resistance training can result in increased bone mineral density in young athletes (Bassey et al. 1994, Borer 2005, Faigenbaum et al. 2009, Faigenbaum et al. 1999, Iwamoto et al. 2009). Research studies indicate that regular participation in sport training combined with resistance training can result in new bone formation for young athletes (Faigenbaum et al. 1999). Consistent participation in a resistance training program can maximize bone mineral density in child and adolescent athletes (Faigenbaum et al. 2009). According to a study from the University of Michigan, physical activity increases growth in width and mineral content of bones in adolescent females when it is initiated before puberty, carried out in volumes and at intensities seen in athletes, and accompanied by adequate caloric and calcium intakes (Borer 2005). A study published in 1994 reported that exercising the weight-bearing skeleton with repeated regular extra loads and a rapidly rising force profile was associated with an increase in bone density in the femur (Bassey et al. 1994).

In addition to decreasing injury risk, data suggests resistance training enhances athletic performance (Faigenbaum 2000, Faigenbaum et al. 2009, Guy et al. 2001, Harries et al. 2012). Improvements in motor performance skills after resistance training in children and adolescents have been observed (Faigenbaum et al. 2009). According to a study published in The Physician and Sports medicine, 2011 Holistic

Training programs that include multifaceted exercise approaches improve biomechanics, sport performance, and injury risk (Myer et al. 2011).

Regular participation in a well-designed resistance training program appears to result in improvement in athletic performance; however, further research is still required in the field of gymnastics. With a progressive need for improved performance and concomitant BMD increase to reduce frequent occurrence of traumatic musculoskeletal injuries to gymnastics participants, a resistance training intervention may provide positive benefits, however current research in only observational (Burt et al. 2012, Burt et al. 2012, Colvin et al. 2010, Emerson et al. 2010, Helge et al. 2002, Maimoun et al. 2011 , O'Kane et al. 2011, Singh et al. 2008, Sobhani et al. 2012). Despite the rapid growth of gymnastics, an extensive database search resulted in only two research publications involving training interventions with this population (Deley et al. 2011, Durall et al. 2009). A study published by Gaelle Deley in 2011 examined the effects of combined electromyostimulation and gymnastics training in prepubertal girls. Christopher Durall researched the effects of preseason trunk muscle training on low back pain occurrence in female collegiate gymnasts. There is no research examining the results of high impact resistance training and its effect on female adolescent gymnasts. There are many studies published in the area of injury prevention and bone mineral density.

Thus, the purpose of this study is to examine the effects of a high impact resistance training protocol on markers of performance and bone mineral density in adolescent female gymnasts. We hypothesize that a resistance training program will result in greater bone mineral density and improved force and power production compared to a control group.

CHAPTER 2

REVIEW OF LITERATURE

Gymnastics and Injury. A review article written by Alexis Colvin and Abigail Lynn in 2010 stated that gymnastics has one of the highest injury rates of all girls sports (Colvin et al., 2010). Colvin cited a study examining the epidemiology of gymnastics related injuries among children in the United States. In this study Singh et al. analyzed data for children 6-17 years old from the National Electronic Injury Surveillance System of the US Consumer Product Safety Commission from 1990-2005. What they found was that an estimated 425, 900 children were treated in US hospital emergency rooms for gymnastics-related injuries over that 15 year period. 82.1% of those being female. The number of injuries sustained per 1000 participants per year differed with age; 7.4 injuries (per 1000 participants per year) for ages 12-17 and 3.6 for ages 6-11 (Singh et al. 2008). Singh et al. concluded that the high incidence of gymnastics-related injuries suggest the need for increased prevention efforts to lower the risk of injury in gymnastics.

O'kane et al. (2011) also examined injury occurrence in gymnastics. This cross-sectional study surveyed 96 female gymnasts ages 7-17 competing from levels 4-10. The results divided injuries into two groups; acute and overuse, as well as accounting for age, competition level, and hour of practice per week. The acute injury rate was 1.3 per 1000 hours while overuse was 1.8 (per 1000 hours) (O'kane et al. 2011). In both cases the incidence of injury increased with age and increasing level of competition with the most common injury occurrence among gymnasts age 13-17, competition levels 7-10, and 19-25 practice hours per week. This presents a need for more preventative measures focusing on the aforementioned group.

A comprehensive review published in 2005 examined the distribution and determinants of gymnastics related injury to date. This study reported similar injury rates (ranging from 1.4-3.7 per 1000 hours) to the two previously mentioned studies. Caine et al. found the majority of injuries were of sudden onset (acute) sprains and strains. However, the pattern of injury onset may vary by location. Lower extremity incurs the most frequent injuries followed by upper extremity and spine/trunk (Caine et al. 2005).

All three of these studies reported significantly greater injury occurrence during competition when compared to practice. However, the majority of injuries occur during practice due to the high exposure hours compared to competition. Increasing injury rates with age and level of competition were also noted with special attention being paid to the higher occurrence of overuse injury among the advanced gymnasts (levels7-10) (Caine et al. 2005, O'kane et al. 2011, Singh et al. 2008).

Female athlete triad. The American College of Sports Medicine's 2007 position stand defines the female athlete triad as the interrelationships among energy availability, menstrual function, and bone mineral density, which may have clinical manifestations including eating disorders, functional hypothalamic amenorrhea, and osteoporosis (Nattiv et al. 2007). The position stand concludes that low energy availability appears to be the factor that impairs reproductive and skeletal health. Energy availability refers to dietary energy intake minus exercise energy expenditure.

In a state of low energy availability cellular maintenance, thermoregulation, growth, and reproduction are affected (Nattiv et al. 2007). This is of special concern in sports that emphasize leanness.

A study done in 2002 out of the University of Western Australia examined the prevalence of disordered eating among elite athletes compared to non-athletes. The subjects were 263 elite male and female athletes competing in 10 different sports and 263 matched non-athlete controls. The athletes were divided into sports with strong emphasis on leanness (thin-build sports) and sports with less emphasis on leanness (normal-build sports). This study included 21 female gymnasts with an average age of 15.5 (SD = 0.81) categorized as a thin-build sport. Researchers concluded that 15% of female athletes in thin-build sports had diagnosed eating disorders (anorexia nervosa or bulimia nervosa) compared to 2% in normal-build sports, and 1% in non-athletes. Also, another 16% of female thin-build athletes showed non-specified disordered eating compared to 6.5% in normal-build and 4.5% non-athletes (Byrne et al. 2002). This demonstrates the risk involved with being an athlete in a sport that emphasizes thin body shape or weight. The demands of a sport to meet a particular body requirement may be enough to lead to disordered eating. For an elite athlete, this behavior may reflect a rational response to pressure to achieve a body shape which will ensure optimal performance (Byrne et al. 2002).

The Clinical Journal of Sports Medicine published a study similar to the Byrne et al. research, however this study examined the prevalence of disordered eating in the entire elite athlete population of Norway. Sundgot-Borgen et al. collected self-reported questionnaires from all of the elite athletes in Norway (N = 1620, female) (N

= 1696, male). The main outcome of this study relevant to gymnastics demonstrated that the prevalence of eating disorders among female athletes competing in esthetic sports (42%) was higher than that observed in endurance sports (24%), technical sports (17%), and ball game sports (16%) (Sundgot-Borgen et al. 2004). The authors concluded that the prevalence of eating disorders (clinical or sub-clinical) is higher in female athletes than male athletes, and more common in leanness-dependent and weight-dependent sports than in others (Sundgot-Borgen et al. 2004).

There are many health concerns associated with the female athlete triad in conjunction with disordered eating, ranging from impaired sports performance to high fracture risk. Of particular concern to gymnasts are the consequences of menstrual irregularities and poor bone mineral density, with risk factors that include (other than disordered eating) high training volumes and low body mass (Nattiv et al. 2007). In 1996 The American Journal of Sports Medicine published research examining risk factors for stress fractures in track and field athletes. This was a twelve month prospective study with a cohort of 111 (53 female, 58 male) track and field athletes between the ages of 17-26. Dual energy x-ray absorptiometry was used to measure total bone mineral content, regional bone density, and soft tissue composition. They also used questionnaires to obtain menstrual characteristics, dietary intake, and training. Bennell et al. found that women who developed stress fractures had significantly lower total bone mineral content as well as lumbar spine and foot bone mineral density. They also had significantly less lean mass in the lower limb, later age of menarche, fewer menses in the year preceding the study, and a lower menstrual index than the non-stress fracture athletes (Bennell et al. 1996). An interesting aside was that when compared to age matched non-athletes, the female athletes with bone injuries has significantly higher lower limb bone mineral density and similar total bone mineral content and lumbar spine bone mineral density. The authors concluded that although bone density is lower in athletes with stress fractures, it nevertheless remains significantly higher at the lower limb and similar at the lumbar spine than that of less active non athletes. This suggests that the level of bone density required by athletes for short term bone health is greater than that required by the general population (Bennell et al. 1996).

Bone Mineral Density and Injury. A case-control study published in 1990 examined whether low bone density and other risk factors for osteoporosis are associated with stress fractures in athletes. This study was one of the first to suggest that low bone density, associated with estrogen deprivation and calcium deficiency (all symptoms of the female athlete triad), may be a risk factor for stress fractures in athletes. In this study Myburgh et al. recruited twenty five athletes with stress fractures during the course of one year. They were matched with control subjects in sex, age, weight, height, number of years participation in their sport, and time spent practicing their sport. What the authors found was; significantly more injured than control subjects had menstrual irregularity (7 and 0 respectively $P < 0.005$) and bone mineral density was lower in injured compared to control subjects in the lumbar spine (1.01 ± 0.14 and 1.11 ± 0.13 g/cm^2 respectively $P = 0.02$) and the proximal femur (0.93 ± 0.11 and 1.0 ± 0.13 g/cm^2 respectively $P = 0.02$) but was significantly lower for injured compared to control subjects in the femoral neck ($P = 0.005$) and Ward triangle ($P = 0.01$) (Myburgh et al. 1990). There was no significant difference in energy intake, or protein, fiber, alcohol, caffeine, vitamin D, or phosphorus. However, there was significantly higher calcium intake by control subjects compared to injured ($P = 0.02$) (Myburgh et al. 1990). The study concluded by suggesting that low bone mineral density in the femoral neck (predominately cortical bone) may be indicative of low bone mineral density (and high risk for stress fracture) in other areas of cortical bone in the lower limbs based on previous findings that young adults show a good correlation between cortical bone mass at various skeletal sites (Myburgh et al 1990). Similar studies have built upon the findings from Myburgh et al. More recently, researchers have focused on drawing a clear conclusion in the relationship between stress fractures and bone mineral density.

A study published in the Archives of Physical Medicine and Rehabilitation in 2000 examined the relationship between bone mineral density and the probability of stress fractures. This study, done by Lauder et al. was a case-control study using 185 active duty women Army soldiers. 27 having stress fracture subjects and 158 no stress fracture controls were interviewed and bone mineral density of the posteroanterior lumbar spine (L2-L4) and femoral neck was measured by means of dual energy X-ray absorptiometry (DXA). The findings for low bone mineral density (BMD) in relation to the probability for stress fracture was found to be significant only after controlling for a variety of confounding variables. The study authors continuously referred to the strong inverse relationship found between femoral neck BMD and the probability of stress fracture. This relationship indicates that lower levels of BMD are associated with an increased likelihood of stress fractures. There were two other variables found to be significantly associated with BMD and the probability of stress fractures;

exercise intensity and body mass index. Though both variables were found to have a positive effect on BMD they were associated with an increased probability of stress fracture. Of particular concern was the finding that exercise duration of greater than or equal to 10 hours per week resulted in greater occurrence of stress fractures (Lauder et al. 2000). The results demonstrated a gradual increase in BMD with increased exercise while also increasing stress fracture occurrence from 12% of participants exercising 5 or less hours per week to 50% exercising 10 or more hours. These findings demonstrate the importance of developing optimal training regimens and controlled exercise to further prevent injury.

Some of the previously mentioned research, as well as many other studies have demonstrated inconclusive results on the impact of BMD on stress fractures, and even more, the effects of the female athlete triad as a whole (disordered eating, menstrual dysfunction, and osteoporosis) on young athletes. In a review on bone density and young female athletes Nichols et al. reported that athletes typically have greater BMD than their counterparts. However, the positive effect of mechanical loading from sport participation may be diminished by their hormonal and nutritional status (Nichols et al. 2007). This idea necessitates examination of a more controlled manner of mechanical loading, regardless of change in hormonal or nutritional status, to see its effect.

As recently as 2005 a review article published in Sports Medicine stated that it is not fully understood how mechanical stimulation influences bone formation, shape, organization, or mineral density and how it interacts with diet and hormones. It has been theorized that the network of osteocytes and periosteal and trabecular lining cells are sensitive to streaming electrical potentials generated when extracellular fluid is forced through the bone canaliculi following compression, bending, or torsion during mechanical loading (Borer, 2005). What is known is that currently BMD is the best non invasive predictor of fracture risk and that small increases in BMD may produce exponential reductions in the relative risk of fractures (Borer, 2005). Changes in BMD occur through the process of internal remodeling. Bone remodeling occurs in response to accumulated defects or microdamage in bone as well as change in nutritional intake and mechanical loading. Once bone longitudinal growth has ceased, changes in bone with and BMD through remodeling become the main form of change in bone mass (Borer, 2005). Rapid increase in BMD in girls occurs in two peaks, between the ages of 13-14, and between ages 16-17. However, these peaks are related to pubertal progression and menarche which in our study population (female adolescent gymnasts) may be inconsistent, as previously recognized in this text.

Resistance training and BMD. In his 1998 review on resistance training and elite athletes, Dr. William Kraemer stated that resistance training has the potential to minimize or offset the incidence of injuries to elite athletes. Furthermore, it may improve the ability to repair and heal damaged tissue (Kraemer et al. 1998). Avery Faigenbaum wrote about the relationship between resistance training and injury prevention, specifically focusing on youth athletes in his article from 2000. He quoted the American College of Sports Medicine saying an estimated 50% of youth athlete overuse injuries could be prevented if more emphasis were placed on the development of fundamental fitness skills, as opposed to sport specific training (Faigenbaum, 2000). In one section of the article, Faigenbaum states that strength training offers a protective effect by improving the strength and integrity of tissue and supporting structures.

In 2001 Nichols et al. published a study on resistance training and bone mineral density in adolescent females. The authors concluded that resistance training is a potential method for increasing bone density in adolescents (Nichols et al. 2001). In this experimental study 67 high school females between the ages of 14-17 were randomly assigned to a training (N = 46) or control (N = 21) group for 15 months. BMD and body composition were measured using DXA and strength was recorded using one repetition maximum protocols for leg press and bench press (performed on Universal weight machines). The training group exercised three days per week following a full body resistance training routine for 30-45 minutes while the control group remained sedentary (≤2 hrs of exercise per week; also baseline requirement to participate in study). Upon completion of the 15 month intervention there were significant improvements in leg strength (40%) and femoral neck BMD (1.035 to 1.073 g/cm^2, $P < 0.01$) for the training group (Nichols et al. 2001). There were no significant changes found in BMD of the lumbar spine or total body measures. This study brought up an important point concerning peak bone mass. Most adolescents are still increasing bone density and have not yet reached peak bone mass (Rico et al. 1992). It was previously unknown whether resistance training would provide significant stimulus to increase BMD beyond the current rate (Nichols et al. 2001).

In their 2009 position stand (a review of the current literature in the field) on youth resistance training, the NSCA concluded that if age-specific resistance training guidelines are followed, and accompanied by proper nutritional intake, a resistance training program can maximize bone mineral density (Faigenbaum et al. 2009). The authors cited 9 studies indicating participation in sports and specialized fitness programs that include resistance training can be a potent osteogenic stimulus in youth. They concluded the section on resistance training and bone health by stating that it appears the osteogenic response to exercise in youth can be enhanced by sensibly prescribing multi-joint, moderate to high intensity resistance training exercises and unaccustomed plyometric exercises (Faigenbaum et al. 2009). They cited one study in particular examining high-impact exercise in preadolescent girls.

That study, published in 1997 by the Journal of Bone and Mineral Research, explored the lean mass, strength, and bone mineral response to a 10-month, high-impact, strength-building exercise program in 71 premenarcheal girls, aged 9–10 years. They examined, lean body mass, BMD (total body, lumbar spine, proximal femur, and femoral neck) using a bone densitometer, and muscular strength (grip and shoulder and knee isokinetic flexion and extension). Following the ten week resistance training intervention there were no differences in height, total body mass, pubertal development, calcium intake, or external physical activity. However, the resistance training group gained significantly more lean mass, less body fat content, greater shoulder, knee and grip strength, and greater BMD in total body (3.5%), lumbar spine (4.8%), proximal femur (4.5%), and femoral neck (12.0%) compared to the controls (Morris et al. 1997). Bone mineral content (BMC) at all sites also increased at a significantly greater rate in the exercise group compared with the controls. Through multiple regression analysis, the authors determined change in lean mass was the primary determinant of BMD accrual. Although a large proportion of bone mineral accrual was related to growth, an osteogenic effect was associated with exercise. They concluded that these results suggest that high-impact, strength building exercise is beneficial for premenarcheal strength, lean mass gains, and bone mineral acquisition (Morris et al. 1997).

When discussing the rationale for resistance training and its effect on BMD and injury prevention it is important to reference the previously mentioned relationship between energy balance, hormonal disturbance (menstrual dysfunction), and bone metabolism also known as the female athlete triad. It has been established that the population at hand, female adolescent competitive athletes, have a heightened risk for one or all of the mechanisms of the triad (Bennell 1996, Byrne 2002, Nattiv 2007). If this were unchanged is there anything that may compensate for the risk of osteoporosis and injury? In their study, published in 2002, Helge and Kanstrup proposed that in a state of diminished estrogen concentration a higher mechanical strain may be needed to maintain BMD (Helge et al. 2002). The purpose of their study was to investigate BMD and the relationships to maximal muscle strength, sex hormone concentrations, and menstrual status. 17 subjects ages 15-20 comprised of 11 elite gymnasts (6 artistic, 5 rhythmic) from the Danish national team, training >15 hours per week, and 6 age matched controls, recruited from upper secondary school, engaged in low impact physical activity <4 hours per week, participated in this study. The subjects completed a questionnaire on exercise activities, health, sport injuries, menstrual status, weight, and diet. BMD was measured for whole body, lumbar spine, proximal femur, and distal radius using DXA. Menstrual blood samples were drawn from the follicular phases between days 0-7 and the luteal phases during the mid luteal phase (defined as period between two thirds of menstrual cycle to four fifths of menstrual cycle). Maximal isokinetic muscle strength was measured in trunk flexion, trunk extension, and left and right knee extension. The results showed that artistic gymnasts had significantly lower body fat than both the rhythmic gymnasts (36% lower, $P<0.01$) and the controls (53% lower, $P<0.001$), while body weight was the same across the three groups. Artistic gymnasts showed 1.9 times lower follicular concentration of serum progesterone than controls ($P<0.05$). BMD of artistic gymnasts was significantly greater ($P<0.05$) than controls at all sites except whole body and higher than rhythmic gymnasts in right ($P<0.01$) and left ($P<0.001$) distal radius. No correlations were found between BMD and menstrual history for artistic gymnasts, however, there was correlation between serum progesterone in follicular phase and whole body BMD ($r = 0.93$), proximal femur BMD ($r = 0.92$), and lumbar spine BMD ($r = 0.89$) (Helge et al. 2002). The authors discussed the idea that based on these results BMD is unrelated to menstrual status but sex hormone concentrations (progesterone and estrogen) may influence BMD in gymnasts with menstrual disturbances. They concluded that in spite of menstrual disturbances it is possible for female gymnasts (specifically artistic) to maintain a BMD that is correlated to maximal muscle strength and falls within normal range or higher (Helge et al. 2002).

Previous gymnastics interventions. There have not been many intervention studies done using female gymnasts, specifically, young female gymnasts. Three studies have been previously published using intervention. Two focused on occurrence of lower back pain and one examined electromyostimulation (EMS) and its effects on strength and power in gymnasts. In 2011 a study written by Deley et al. was published in the

Journal of Strength and Conditioning Research. This study examined the effects of a 6-week combined EMS and gymnastics training program on muscle strength and vertical jump performance in prepubertal gymnasts. The participants were 16 prepubertal national or regional gymnasts with no history of knee injury. They were randomized into the EMS group (N = 8) or control group (N = 8). The EMS group underwent 6 weeks of EMS performed bilaterally on the knee extensor muscles. The protocol was 20 minutes three times per week for the first three weeks, then once a week for 20 minutes weeks 4-6. Testing was performed on maximal voluntary torque (MVT) of the knee extensors (week 0, 3, 6) and vertical jump tests (week 0, 3, 6, 10). Deley et al. discovered that after only three weeks of EMS training the MVT had improved significantly from baseline in the training group ($P < 0.05$) (Deley et al. 2011). However, following the three week point no further increase was demonstrated. There was no significant MVT change in the control group. The subjects also demonstrated significant improvement in the vertical jump tests at 3 weeks ($P < 0.05$) and 6 weeks ($P < 0.05$). The lack of change in the control group following this study demonstrates that significant improvement is a result of the training intervention and not regular growth in the population (Deley et al. 2011).

The other two intervention studies with a gymnastics population examine the effects of different exercise interventions on the occurrence of lower back pain. In 2007, a prospective controlled intervention study evaluated a specific segmental muscle training program of the lumbar spine in order to prevent and reduce low back pain in young female gymnasts. The participants were 42 (N = 51 with 9 dropouts) female adolescent gymnasts (ages 11-16). The intervention group (N = 30) performed the training program, which involved progressing difficulty of abdominal hollowing 3-4 times per week for 8 weeks. The control group (N = 12) continued their normal gymnastics training for the duration of the study. All participants were asked everyday if they had experienced any lower back pain, and if they had to mark the spot on a pain map. The gymnasts participating in the intervention group reported significantly less days with low back pain compared to baseline (P = 0.02) (Harringe et al. 2007).

The second study examining occurrence of low back pain was published by Durall et al. in 2009. In this study the authors examined the effects of preseason trunk muscle training on low-back pain occurrence in women collegiate gymnasts. The participants were 15 NCAA Division III female gymnasts (training group) and 15 female non-athlete college students (control). The training group performed 15 minutes of trunk muscle training twice per week for 10 weeks during their preseason gymnastics training. All participants were pre and post tested in four trunk static hold tests. Following the 10 week intervention the training group showed significant improvements in all 4 static hold tests (P < 0.0005) while the control demonstrated improvement in trunk flexor endurance, but no significant improvement (Durall et al. 2009).

It is worth noting that this study included a seemingly big limitation. The authors used the entire gymnastics team for their study because they did not want to leave any of the athletes out of the training intervention. This meant that their control group was not participating in the same normal gymnastics training as the training group. Due to this, the results of this study may be misleading.

Addition to the literature. All three of the previously mentioned intervention studies were successful using a young female gymnast population to examine the effects of a training routine on pain/injury and strength/power. While their aim differs from a resistance training intervention examining the effects on BMD, tendon thickness, strength and power, they are useful to demonstrate experimental design, statistical analysis, and opportunities for future research within the population. The research used in this review of the literature has demonstrated the potential health risks associated with young female gymnastics participation including low energy availability, menstrual dysfunction, low bone mineral density, and high risk of injury. It has also demonstrated the potential benefits of a well planned and implemented resistance training routine to improve bone mineral density, help prevent the occurrence of injury, and improve performance. There is a definite need to explore different avenues of reducing the health risks in that population. The aim of this study is to examine the effects of resistance training on bone mineral density, tendon thickness, and performance in young female gymnasts.

CHAPTER 3

METHODOLOGY

Study Design: Adolescent female gymnasts were recruited from a local Junior Olympic club team to participate in a 10 week resistance training intervention examining its effects on bone mineral density (BMD) and markers of performance. Participants attended a single informational meeting where parents signed informed consent (Appendix I). Participants signed the underage assent form (Appendix II).

Participants: Sixteen young female gymnasts competing at USA Gymnastics Junior Olympic levels 7-10 recruited from local club team Aim High Academy, 3355 South County Trail, East Greenwich, RI 02818. Participating in resistance training (RT) (N = 10 age; 13.5±1.00 years, height; 155.19±8.38 cm, weight; 51.58±9.63 kg, body fat %; 23.57±2.68%, lean body mass; 39.31±7.64 kg) or gymnastics training only (GT) (N = 6 age; 15.25±2.25 years, height; 149.23±11.91 cm, weight; 46.52±10.22 kg, body fat %; 25.83±2.93%, lean body mass; 34.69±7.46 kg) (Table 1). To be included all participants had to be at least 12 years old by the date of pre testing, practice more than 15 hours per week, compete within the USA Gymnastics Junior Olympic levels 7-10, and maintain full gymnastics participation (without injury) throughout the duration of the study. Participants were excluded if they did not meet all of the previous criteria. Gymnastics competition levels are assigned based on individual skill completion following rules of the governing body of USA Gymnastics. Levels are achieved regardless of age, multiple age groups may participate at the same competitive level.

Procedures: After IRB-approved parental and subject consent was given, participants were randomized into one of two groups; resistance training (RT) or control group, gymnastics training only (GT). Both groups participated in pre and post testing (Appendix III) for bone mineral density (BMD), body composition, strength testing, power testing, and ultrasonography of both Achilles and Patellar tendon thickness. Participants in the RT group participated in an alternating two day a week, 10 week non-linear periodized resistance training program while continuing their usual gymnastics training routine. Participants in the GT group continued their usual gymnastics training routine within the normal hours of practice. Groups were matched on competitive level and age. Usual gymnastics training includes practice 4-6 days per week totaling 16-25 hours total.

***Anthropometric Measures*:** Age and level were recorded. Height and weight were measured using a physician scale (Detecto Weigh Beam Eye Level, Webb City, MO) during pre- and post- testing.

Bone Mineral Density and Body Composition: Body composition, BMD, and bone mineral content (BMC) were assessed using dual-energy x-ray absorptiometry (DXA) during pre- and post-testing. Whole body scans using a fan-beam densitometer with accompanying software (Lunar iDXA, GE Medical Systems, Wauwatosa, WI) recorded total body estimates of percent fat, areal bone mineral density, bone mineral content, fat percentage and mass, and non-bone lean tissue were determined using manufacturer described procedures and supplied algorithms.

Power Testing: Briefly, subjects performed a warm-up on a cycle ergometer followed by light dynamic stretching (Appendix IV). Vertical jump power was assessed using a force plate and associate software (Accupower, Advanced Mechanical Technologies Inc., Watertown, MA). After familiarization, subjects were asked to stand in the center of the force plate and place their hands on their hips and jump as high as they could for 3 subsequent continuous repetitions, each subject completed 3 sets of 3 jumps. The highest power and height for each set was recorded during pre- and post-testing.

Strength Testing: Following power testing, one repetition maximum (1-RM) strength was assessed in the bench press and squat exercises as previously demonstrated by Comstock et al. 2011. Beginning with the squat exercise subjects then performed 8-10 repetitions at ~50% of estimated 1-RM, followed by another set of 3-5 repetitions at ~85% of 1-RM. Three to four maximal trials separated by 2-3 minutes of rest were used to determine individual 1-RM for each resistance exercise. 1-RM testing was performed at pre- and post-testing.

Dietary Intake: Subjects completed a 1-day dietary recall prior to and after the intervention period. Nutritional data was entered into *Food Processor* (ESHA Research, Salem, OR) and analyzed for multiple variables by Joanna Procopio, MS, RDN, LDN (Table 4).

Resistance Training Intervention: Subjects in the RT group continued normal gymnastics training as well as participating in resistance training on 2 non-consecutive days each week for ten weeks (Appendix V). The resistance training program followed a non-linear periodization model in which load and repetition were varied on a weekly basis. All training sessions began with the same dynamic warm up from pre- and post-testing. During the initial training (weeks 2-6), "light" days consisted of 12 RM loads, "moderate" days consisted of 8-10 RM loads, and "heavy" days consisted of 6-7 RM loads. During weeks 7-11, "light" days consisted of 12 RM loads, "moderate" days consisted of 6-8 RM loads, and "heavy" days consisted of 3-5 RM loads (Appendix VI). The exercises were divided into two 5 week phases (Phase 1 weeks 2-6, Phase 2 weeks 7-11). Each workout day focused on a full body routine comprised of high impact movements using large amounts of muscle mass in the upper and lower body (Appendix VII).

Gymnastics Training: All participants in the GT group continued their regular gymnastics training.

Statistical Analysis: A linear model with a two-way mixed factorial analysis of variance (ANOVA) (i.e., groups X time) was run with a Bonferroni post-hoc test when main effects occurred. An ANCOVA was run to correct for age and height for bone measures. Linear assumptions were tested and confirmed. Significance was set at $p \leq 0.05$.

CHAPTER 4

FINDINGS

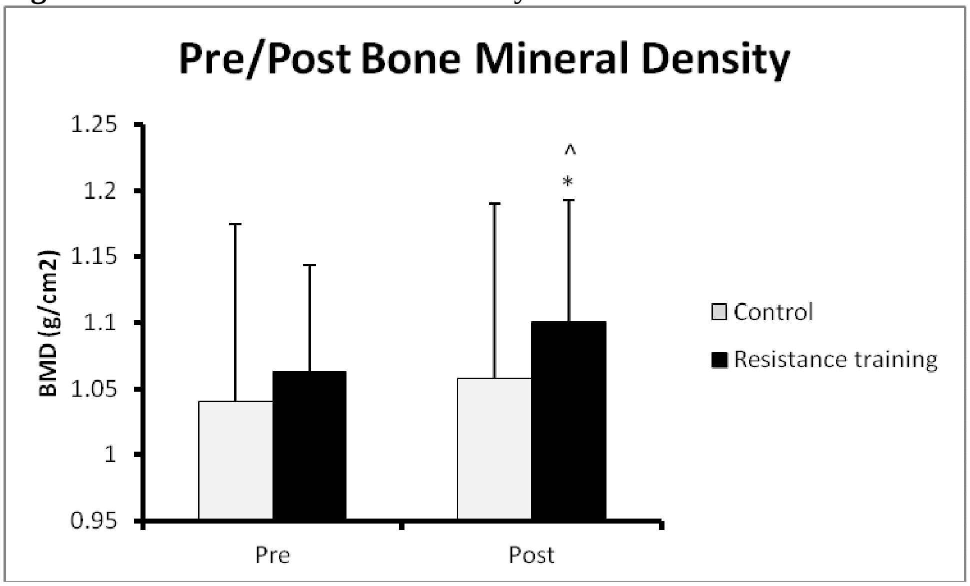
Table 1. Anthropometric measures by group (mean±SD)

	RT		**GT**	
	Pre	Post	Pre	Post
N	10	10	6	6
Age (years)	13.5±1	13.5±1	15.25±2.25	16.00±2.00
Height (cm)	155.19±8.38	156.72±7.65	149.23±11.91	152.19±11.87
Weight (kg)	51.58±9.63	52.77±9.43	46.52±10.22	47.05±9.68
BF (%)	23.57±2.68	24.30±2.53	25.83±2.93	23.75±3.28
LBM (kg)	39.31±7.64	39.60±7.44	34.69±7.46	36.06±7.94
Comp. level	7-10	7-10	7-9	7-9

RT = Resistance training group (experimental), GT = Gymnastics training group (control), N = number of participants, (cm) = measure in centimeters, (kg) = measure in kilograms, BF (%) = body fat content measured as a percentage of total body mass, LBM = lean body mass, Comp. level = USA Gymnastics junior Olympic athlete designation for level of competition

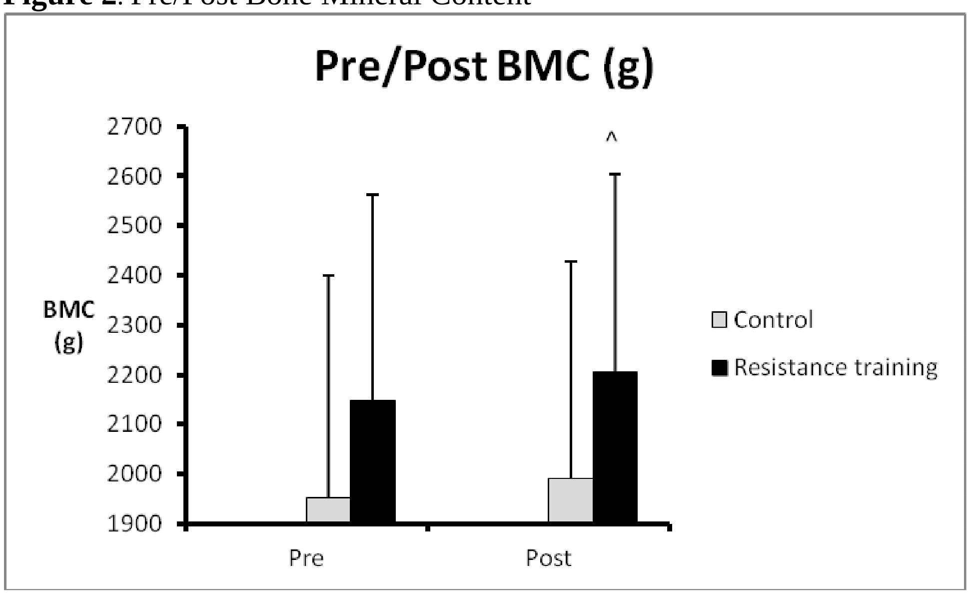
Bone measures: The RT group demonstrated significantly greater ($p \leq 0.05$) BMD (g/cm²) following the intervention compared to pre values and post-GT values (Figure 1) when height and age were corrected for. The RT group demonstrated significantly greater ($p \leq 0.05$) BMC (g) following the intervention compared to pre values. There was no significance in BMC (g) following intervention compared to post-GT values (Figure 2).

Figure 1. Pre/Post Bone Mineral Density



BMD (g/cm²) = measurement of bone mineral density in grams per square centimeter, ^ denotes significant difference from pre value in corresponding group ($p \leq 0.05$), *****denotes significant difference from GT group are corresponding time point (($p \leq 0.05$).

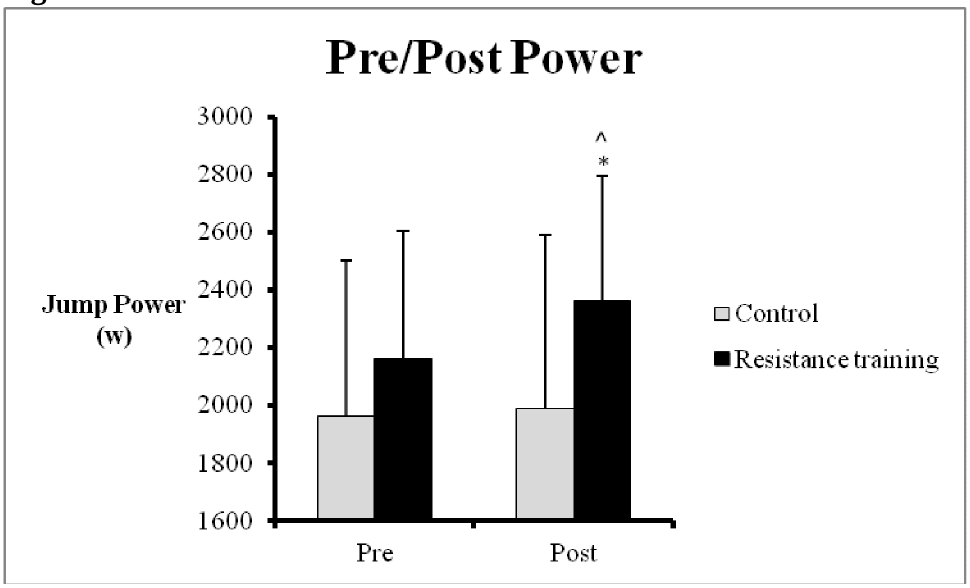
Figure 2. Pre/Post Bone Mineral Content



BMC (g) = Bone mineral content as measured in grams, ^denotes significant difference from pre value in corresponding group ($p \leq 0.05$).

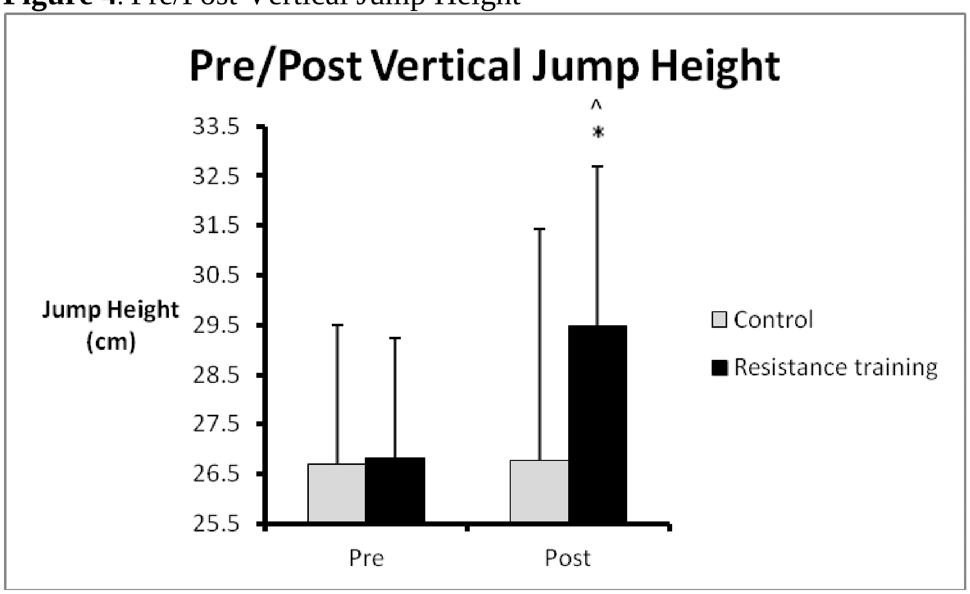
Power: The RT group demonstrated significantly greater ($p \leq 0.05$) power (W) (Figure 3) and vertical jump height (cm) (Figure 4) following the intervention compared to pre values and post-GT values.

Figure 3. Pre/Post Power



(W) = measurement in watts, ^ denotes significant difference from pre value in corresponding group ($p \leq 0.05$), *****denotes significant difference from GT group are corresponding time point (($p \leq 0.05$).

Figure 4. Pre/Post Vertical Jump Height



(cm) = measurement in centimeters, ^ denotes significant difference from pre value in corresponding group ($p \leq 0.05$), *****denotes significant difference from GT group are corresponding time point (($p \leq 0.05$).

Strength: The RT group demonstrated significantly greater ($p \leq 0.05$) strength in the 1RM squat (kg) and bench press (kg) (Table 2) following the intervention compared to pre values and post-GT values.

Table 2. 1RM strength and squat and bench press (mean±SD)

	RT		GT	
	Pre	Post	Pre	Post
Squat (kg)	56.59±9.43	68.94±16.74^*	67.42±18.16	55.05±9.90
Bench Press (kg)	37.95±6.43	44.70±7.45^*	35.99±10.20	35.48±10.22

RT = Resistance training group (experimental), GT = Gymnastics training group (control), (kg) = measure in kilograms, ^ denotes significant difference from pre value in corresponding group ($p \leq 0.05$), *****denotes significant difference from GT group at corresponding time point ($p \leq 0.05$).

Body composition: Other than significant difference ($p \leq 0.05$) in BMD (g/cm^2) and BMC (g), there was no significance found in measures of body composition for BM (kg), BF (%), or LBM (kg) (Table 3).

Table 3. Body composition data (mean±SD)

	RT		GT	
	Pre	Post	Pre	Post
BM (kg)	51.58±9.63	52.77±9.43	46.52±10.22	47.05±9.68
BF (%)	23.57±2.68	24.30±2.53	25.83±2.93	23.75±3.28
LBM (kg)	39.31±7.64	39.60±7.44	34.69±7.46	36.06±7.94
BMD (g/cm^2)	1.06±0.08	1.10±0.09	1.04±0.13	1.06±0.13
BMC (g)	2148.15±413.27	2204.32±400.63	1951.20±447.98	1991.13±436.02

RT = Resistance training group (experimental), GT = Gymnastics training group (control), BM = body mass, (kg) = measurement in kilograms, BF (%) = body fat content measured as a percentage of total body mass, LBM = lean body mass, BMD (g/cm^2) = measurement of bone mineral density in gram per square centimeter, BMC (g) = measurement of bone mineral content in grams.

Dietary intake: The GT group demonstrated significantly less ($p \leq 0.05$) Fat intake when compared to the RT group at corresponding time points. The GT group also demonstrated significantly greater ($p \leq 0.05$) Vitamin D intake compared to the RT group at corresponding time points. No other significant difference in dietary intake was found (Table 4).

Table 4. Nutrition data pre- and post- (mean ±SD)

	RT		GT	
	Pre	Post	Pre	Post
Calories (kcal)	1901.35±596.51	1676.66±446.56	1770.89±723.98	1425.60±252.40
Protein (g)	82.07±29.39	79.56±33.33	88.98±27.48	87.27±24.84
Carbohydrate (g)	247.95±96.55	204.53±50.06	246.30±111.88	188.00±61.03
Fat (g)	66.62±19.48	63.79±21.97	51.42±27.64	39.64±17.05*
Vitamin D (IU)	94.43±109.15	50.20±60.22	168.53±167.93	143.35±102.16*
Calcium (mg)	998.27±374.88	1156.04±740.88	1197.68±832.43	788.59±249.53

RT = Resistance training group (experimental), GT = Gymnastics training group (control), kcal = measurement in kilocalories, (g) = measurement in grams, IU = measurement in international units, mg = measurement in milligrams, *denotes significant difference from RT group at corresponding time point ($p \leq 0.05$).

CHAPTER 5

DISCUSSION

This study examined the effects of a high impact resistance training protocol on markers of performance and bone mineral density in adolescent female gymnasts. Major findings included significant improvements ($p \leq 0.05$) in total body bone mineral density, vertical jump power, and vertical jump height following a 10-week resistance training intervention.

Results from this study demonstrated significant increase in total body BMD (3.78%) for the resistance training group compared to the gymnastics training group. Previous studies have demonstrated mixed results in their findings. Morris et al. found significant increase in total body BMD (3.5%) in premenarcheal girls following a ten month, high impact, exercise intervention (Morris et al. 1997). However, in a different study, Nichols et al. found no significance in total body BMD in adolescent females following a fifteen month resistance training intervention, even though there was increase of 2.81% in total body BMD (Nichols et al. 2001). Both studies found significant increases in BMD for the resistance training groups, following their interventions, when measuring BMD at specific anatomical sites. For our study total body BMD was measured because of time constraints and to allow for minimal radiation exposure. This allowed data to be collected with one full body scan, rather than one full body scan plus multiple site specific scans.

Reviews examining the effects of resistance training or high impact exercise on BMD have recommended interventions of longer than or equal to six months duration (Borer et al. 2005, Iwamoto et al. 2009). The previously mentioned studies by Morris et al. and Nichols et al. used interventions lasting much longer than the ten week time frame used in this study. Nichols et al. 2001 used progressive resistance training three times per week for fifteen months (Nichols et al. 2001). Morris et al. used high impact exercise for thirty minutes three times per week for ten months (Morris et al. 1997). Bassey et al. 1994 used high impact exercise once per week for 6 months (Bassey et al. 1994). Competitive gymnastics is time consuming. Participants spend between 20-30 hours per week practicing and competing, on top of school and homework. This study demonstrates that there can be significant increase in BMD in only ten weeks with one hour of high impact resistance training twice a week in this population. Dr. Clifford Rosen provides a possible explanation for this in his chapter from *The Endocrine System in Sports and Exercise* where he explains that during adolescence, when bone growth is in full force, high impact loading results in greater changes in BMD than any other period of bone growth (Rosen, 2005). These athletes were participating in this study during a period of rapid bone turnover. This further emphasizes the importance of resistance training for this population.

Numerous studies have demonstrated the strong correlation between low BMD and injury (Myburgh et al. 1990, Lauder et al. 2000, Borer, 2005). Improving BMD is important because female adolescent gymnasts are at high risk for the detrimental effects of the female athlete triad and overuse or traumatic injury (Colvin et al. 2010, Ducher et al. 2009, Myer et al. 2011, Singh et al. 2008, Soric et al. 2008, Warren et al. 1999). These studies further emphasize the potential benefit that would come from participating in planned resistance training to increase bone mineral density and reduce their risk of injury (Abernathy et al. 2007, Faigenbaum et al. 2009, Kraemer, 2009, Nichols et al. 2007).

Besides reduced injury risk, there are also potential performance implications for gymnasts gained through supplemental resistance training. Many studies show that resistance training enhances athletic performance (Faigenbaum et al. 2009, Guy et al. 2001, Harries et al. 2012, Myer et al. 2011). Previously there has only been one intervention study examining performance measures in female gymnasts. Deley et al. saw significant increase in vertical jump performance (height) and muscular strength following a 6-week combined electromyostimulation and gymnastics training intervention using 16 female adolescent gymnasts (Deley et al. 2011). Our study demonstrated significant increase ($p \leq 0.05$) in vertical jump performance for power and height, as well as improvements in maximal muscular strength. Gymnastics skill progression requires large amounts of strength and power. Scores are given based on inclusion of specific skills as well as overall amplitude and cleanliness of the routine. The demonstrated increase in strength, power, and jump height from this study will supply a direct advantage to participants while competing.

When training for performance improvement and bone remodeling it is important to organize resistance training routines in a specific manner. The method of periodization (non-linear) used in this study has been shown to result in greater performance gains over traditional linear periodization models (Faigenbaum et al. 2009, Prestes et al. 2009, Smith et al. 2013). A periodized model was used to optimize adaptations, and to prevent boredom and overtraining. Exercises involving muscles of the whole body were incorporated to develop overall muscle strength and power (Faigenbaum et al. 2009, Lester et al. 2009, Smith et al. 2013). The exercises and load ranges performed during the study have also been specifically chosen in order to impact lower body bone remodeling (Lester et al. 2009). Based on our prior work, it was our belief that the load ranges and exercises selected would be effective for augmenting physical performance (i.e. strength and power) and that within this paradigm a great deal of bone remodeling would occur (Rosen, 2005).

Including dietary intake data with this study was done to demonstrate that the results were due to the intervention and not because of significant differences in nutritional consumption between groups. Though Vitamin D intake was significantly higher in the GT group on their post testing dietary recall, there were still significant BMD improvements in the RT group. Although it is well documented that bone remodeling is effected by Vitamin D and Calcium intake, the resistance training protocol was of sufficient intensity to overcome these important nutritional differences (Bonjour, 2005).

Importantly, this study was feasible. The participant population has very limited time outside of gymnastics practice and school. It is also a population that traditionally does not participate in specific resistance training outside of gymnastics practice. Qualitatively, conversations with both participants and coaches revealed that the athletes participating in the RT group enjoyed the training sessions and would like to continue to follow a resistance training program. Participants said that they could see and feel a difference in the body and gymnastics performance during and following the intervention. Coaches said there was noticeable power increases in the athletes skills, particularly their vaulting and tumbling. These are important things to consider when assessing the results of this study.

Limitations: The results of this study analyzed measurements of total body BMD through use of DXA. Previous studies have documented the possibility of error in total body measurements. Many have used specific anatomical site measurements such as lumbar spine and femoral neck to collect data (Borer et al. 2005, Burt et al. 2012, Ducher et al. 2009, Nichols et al. 2007, Taffee et al. 1997). However, due to time and financial constraints we chose to examine total body BMD and still demonstrated significant results.

During the statistical analysis process height and age were corrected for in BMD measures because of the differences in growth and age between the RT group and GT group. A review published by Katrina Borer in 2005 provides a possible explanation. She found that adolescents experiencing growth spurt, growth of bone in width must be considered when areal BMD assessment methods are used to avoid identification of bone size differences. The review concluded that areal measurements of BMD may be misleading if changes in bone size are not taken into account. Volumetric BMD estimates from DXA measurements in girls during pubertal growth indicate that the accretion of bone mineral proceeds primarily through increases in bone size rather than by increases in BMD (Borer 2005). Controlling for pubertal bone growth during the analysis allowed the results to demonstrate significant improvements in BMD for RT compared to GT. Higher pubertal growth rates in the GT group may have been disguised as accretion of BMD had we not controlled for that.

Conclusion: This study was the first to examine the effects of a resistance training intervention on both BMD and performance in female adolescent gymnasts. Statistical analysis demonstrated significant increase in BMD as well as vertical jump height and power in only ten weeks. The time commitment and intervention protocol used was well tolerated by the athletes, which is an important factor with this population. Further, we found no significant changes in weight or body composition, with the improved BMD and performance, which is a major consideration in this aesthetically driven sport where participants fear weight gain. Further research should examine BMD changes at specific anatomical sites, specifically; lumbar spine, pelvis, femoral neck, and distal femur. A study combining resistance training and nutritional supplementation would also be beneficial to this population.

Practical applications: Full body, high impact resistance training performed on non-consecutive days, following non-linear periodization for 1.5 to 2 hours per week for ten weeks is sufficient to obtain bone mineral density and performance improvements in competitive female adolescent gymnasts.

APPENDICES

Appendix I

PARENTAL PERMISSION FORM FOR RESEARCH

The University of Rhode Island
Department of Kinesiology
Kingston, RI 02881

Impact of Strength Training on Bone Mineral Density, Tendon thickness, and Performance in Competitive Female Gymnasts

Your daughter has been invited to take part in a research project described below. Our names are Disa Hatfield, Andy Procopio, and Justin Nicoll and we are asking for permission to include your daughter in this study because we hope to make important discoveries about the connection between resistance training and competitive gymnastics through this research, and we cannot do it without your help.

Description of the project:
The purpose of this study is to discover how working out with weights might change your daughter's bone strength, ankle and knee tendon thickness, and how it might make her stronger and improve competition scores. There will be many safeguards throughout this study to reduce and prevent risk or discomfort for your daughter. If at any point in this study your daughter feels uncomfortable or does not want to participate anymore please do not hesitate to tell one of us.

What will be done:
If you allow your daughter to participate, they will be part of the study for 16 weeks. They might be participating in a strength training routine and gymnastics, a plyometric training routine and gymnastics, or just continuing their usual gymnastics routine. She will be tested on the density of her bones, muscle strength and how she can jump, as well as the thickness of her Achilles tendon (behind her ankle) and patellar tendon (on top of her knee cap) at the beginning and end of the 16 weeks.

This is what we will be done on one visit before and one visit after the 16 week training:

- We will ask your daughter to fill out a medical health history form to find out if she has any injuries that would prevent her from participating in this study.

- We will measure her height and weight with a normal scale and measurement tape.

- Her bone mineral density will be measured using dual energy x-ray absorptiometry or DEXA. DEXA uses two low energy x-rays which scan the body and determine body composition, including bone mineral density. Even though the DEXA uses two x-rays the energy of the x-rays is very low, and radiation exposure is significantly lower than a typical x-ray. The amount of radiation she will be exposed to on each visit is comparable to visiting New York City for a day, and is slightly less than a normal chest x-ray. Even though the DEXA emits only small amounts of radiation, as a precaution often used with x-ray testing, women who are pregnant may not participate to prevent harm to the fetus. For that reason, we are required to ask your daughter to give us a urine sample to do a pregnancy test, even if she does not think there is a reason to do one.

- For the DEXA scan, she will be asked to change into a set of medical scrubs, and lay flat on the DEXA panel. The scan takes place on an open table; she will never be enclosed at any point. A strap will be placed around her ankles to aid in maintaining proper body position during the scan. She will lie as still as possible while an arm which emits the x-rays passes over her body and scans it. A typical DEXA scan lasts approximately 10 minutes.

- We are going to use an ultrasound to measure how thick her ankle and knee tendons are. For the ankle test, we will ask her to stand up as she normally would and we will put a small plastic device called a probe on the back of her heel and calf muscle. There will be a gel on the probe which might be a little cold, but it wipes right off. For the knee test, we will do the same thing, only the probe will be placed right above her knee-cap. Each of these tests will only take a minute and she won't feel anything.

- After she completes these tests, we will want to measure how strong she is and how high she can jump. To measure her strength, we will ask her to do a squat exercise and a bench press exercise. Before she does these exercises, she can warm-up on a stationary bike and do some dynamic stretches (which we will show her). After that, we will ask her to squat progressively higher amounts of weight. We will show her how to do the exercise and will only increase the weight if she is doing the exercise safely and correctly. She will have 2-3 minutes of rest between each squat. We will ask her to do the same thing with a bench press. For both of these tests, she can ask to stop at anytime she feels uncomfortable or if she feels like she can't lift any more weight. One of us will always be spotting while she lifts, for safety.

- To measure jump height and power, we will ask her to perform 3 jumps in a row as high and as fast as she can on a platform that will record her power and jump height. We will ask her to do that 3 times, resting in between each 3-jump set, so we can use her best scores.

These two visits will take about an hour and 15 minutes each time.

After the first testing day, we will divide the participants up into three groups, a resistance training group, a plyometric training group, and a control group. If she does not already participate in the plyometric training at her gym, she will be placed in the control group and will simply go about her normal gymnastics training. Some of the girls will be asked work out with weights for 16 weeks. If they are asked to be in that group, they will replace their normal plyometric training time with weight training. We will ask your daughter to either come to the gym at U.R.I. (the same place they did their testing) to train or to go to Next Level Fitness Center in Johnston, RI twice a week to work out for one hour. Your daughter can choose to train at whichever gym is more convenient to her. One of us will always be there to help with her training and make sure she is lifting weights properly. For gymnastics training, she will continue to follow her normal routine. If she is not asked to do resistance training, she will continue with her normal gymnastics and plyometric training at her regular gym.

At the end of the 16 weeks, we will ask your daughter to come back to the lab at U.R.I and repeat the same tests she did at the beginning of the study.

In order to be part of this study, she has to be a female competitive gymnast with at least a level 7 rank. She also has to be between the ages of 12 and 20, and not have any current injuries.

Risks or discomfort:
Exercise and physical effort can cause soreness or injury from overexertion and/or accident. With strength and jump height testing, some risks exist for muscle strain or pulls of the exercised musculature, muscle spasm, and in extremely rare instances, muscle tears. Some muscle soreness may be experienced 24 to 48 hours after exercise from muscular strength and power testing. That soreness should disappear completely within a few days and have no long-lasting effects.

There are some risks to having bone density tested because a DEXA uses a similar kind of radiation that an x-ray does. Total radiation exposure for the whole study (one DEXA before and after the study) is almost the same as one and a half chest x-rays or four cross-country flights.

There are no known risks for the ultrasound test.

Benefits of this study:
Benefits of this study include potentially decreasing your daughters risk for injury. She will learn how strong she is and how healthy her bones and tendons are. In addition

she will also be adding knowledge to her sport and will give her and her coaches better opportunity to understand and make better training programs for her to follow during her gymnastics season.

Confidentiality:
Your part in this study is confidential. No one else will know if you were in this study and no one else can find out what answers you gave. We will keep all the records for this study and we will be the only people to have access to these records. The documents will be stored in a locked file cabinet in suite 220 in Independence Square on the URI campus. The records will be kept for 7 years and then destroyed.

In case there is any risk of injury to the subject:
Chance of injury while participating in this study is very small, however, due to the strength testing as well as the resistance training and plyometric training groups there is always a small chance of getting hurt. It is not the policy of the University of Rhode Island to compensate subjects in the event that a research procedure results in physical or psychological injury. The University of Rhode Island will, however, make its best effort to refer your daughter to appropriate services, upon request, if injury does occur. You may discuss this with Andy, Justin, or Disa Hatfield. However, if your daughter experiences any problems related to this study you should contact her personal physician. In that case they must immediately report what hurts to whoever is working with them at that time. We will then follow the necessary steps to get her taken care of, beginning with contacting any emergency medical service necessary. In the case of an injury that is discovered while at home, school, or practice please contact us to let us know. Our phone number is (401) 874-5183. You may also call the office of the Vice President for Research, 70 Lower College Road, University of Rhode Island, Kingston, Rhode Island, telephone: (401) 874-4328.

Decision to quit at any time:
Your daughter might want to talk to you before deciding whether or not to be in this study. The decision to be part of this research is up to you and her. She does not have to participate. We require parents to give her permission to take part in this study. If she does decide to participate, she can always drop out of the study at any time. Whatever she decides will not be held against her in any way. No one will be upset if she does not want to participate or even if she changes her mind later and wants to stop. If she wants to quit the study, just let one of us know. Our number is (401) 874-5183.

Your rights as a participant:
If you are not satisfied with the way this study is performed, you may discuss your complaints with Disa Hatfield, Andy Procopio, or Justin Nicoll at (401) 874-5183, anonymously, if you choose. In addition, if you have questions about your rights as a research participant, you may contact the office of the Vice President for Research, 70 Lower College Road, Suite 2, University of Rhode Island, Kingston, Rhode Island, telephone: (401) 874-4328.

Remember, you can ask any questions you may have about this study. If you have a question later that you didn't think of now, you can call one of us at (401) 874-5183 or ask me next time. Would you like to read or hear about this study a second time before you decide?

Signing your name at the bottom of this form means that you have read or listened to what it says and you understand it. Signing this form also means that you agree to allow your daughter to participate in this study and your questions have been answered. You will be given a copy of this form after you have signed it.

____________________________	____________________________
Signature of Parent	Signature of Researcher
____________________________	____________________________
Typed/printed Name	Typed/printed name
____________________________	____________________________
Date	Date

Please sign both consent forms, keeping one for yourself

Appendix II

ASSENT FORM FOR RESEARCH

The University of Rhode Island
Department of Kinesiology
Kingston, RI 02881

Impact of Strength Training on Bone Mineral Density, Tendon thickness, and Performance in Competitive Female Gymnasts

Our names are Disa Hatfield, Andy Procopio, and Justin Nicoll. We are inviting you to take part in a research study because we are trying to learn more about how strength training and gymnastics strengthens your bones and tendons and makes you a better gymnast. We will explain the project to you in detail. You should feel free to ask questions. If you have more questions about this study later, please call Disa Hatfield, Ph.D., Andrew Procopio, or Justin Nicoll, the persons responsible for this study, at (401)-874-5183.

Description of the Project:

The purpose of this study is to discover how working out with weights might change your bone strength, ankle and knee tendon thickness, how it might make you stronger and improve your competition scores. There will be many safeguards throughout this study to reduce and prevent risk or discomfort for you. If at any point in this study you feel uncomfortable or don't want to participate anymore please do not hesitate to tell one of us.

What will be done:

If you agree to be in this study, you will be asked to participate for 16 weeks. You might be participating in a strength training routine and gymnastics, a plyometric training routine and gymnastics, or just continuing your usual gymnastics routine. You will be tested on the density of your bones, muscle strength, jumping ability, and the thickness of your Achilles tendon (behind your ankle) and patellar tendon (on top of your knee cap) at the beginning and end of the 16 weeks.

This is what we will ask you to do on one visit before and one visit after the 16 week training:

- We will ask you fill out a medical health history form to find out if you have any injuries that would prevent you from participating in this study.

- We will measure your height and weight with a normal scale and measurement tape.

- Your bone mineral density will be measured using dual energy x-ray absorptiometry or DEXA. DEXA uses two low energy x-rays which scan the body to determine body composition, including bone mineral density. Even though the DEXA uses two x-rays the energy of the x-rays is very low, and radiation exposure is significantly lower than a typical x-ray. The amount of radiation you will be exposed to on each visit is comparable to visiting New York City for a day, and is slightly less than a normal chest x-ray. Even though the DEXA emits only small amounts of radiation, as a precaution often used with x-ray testing, women who are pregnant may not participate to prevent harm to the fetus. For that reason, we are required to ask you to give us a urine sample to do a pregnancy test, even if you don't think there is a reason to do one.

- For the DEXA scan, you will be asked to change into a set of medical scrubs, and lay flat on the DEXA panel. The scan takes place on an open table; you are never enclosed in at any point. A strap will be placed around your ankles to aid in maintaining proper body position during the scan. You will lie as still as possible while an arm which emits the x-rays passes over your body and scans it. A typical DEXA scan lasts approximately 10 minutes.

- We are going to use an ultrasound to measure how thick your ankle and knee tendons are. For the ankle test, we will ask you to stand up as you normally would and we will put a small plastic device called a probe on the back of your heel and calf muscle. There will be a gel on the probe which might be a little cold, but it wipes right off. For the knee test, we will do the same thing, only the probe will be placed right above your knee-cap. Each of these tests will only take a minute and you won't feel anything.

- After you do these tests, we will want to measure how strong you are and how high you can jump. To measure your strength, we will ask you to do a squat exercise and a bench press exercise. Before you do these exercises, you can warm-up on a stationary bike and do some dynamic stretches (which we will show you). After that, we will ask you to squat progressively higher amounts of weight. We will show you how to do the exercise and will only increase the weight if you are doing the exercise safely and correctly. You will have 2-3 minutes of rest between each squat. We will ask you to do the same thing with a bench press. For both of these tests, you can ask to stop at anytime you feel uncomfortable or if you feel like you can't lift any more weight. One of us will always be spotting you while you lift for safety.

- To measure jump height and power, we will ask you to perform 3 jumps in a row as high and as fast as you can on a platform that will record your power and jump height.   We will ask you to do that 3 times, resting in between each 3-jump set, so we can use your best scores.

These two visits will take about an hour and 15 minutes each time.

After the first testing day, we will divide you up into three groups, a resistance training group, a plyometric training group, and a control group. If you don't already participate in the plyometric training at your gym, you will be placed in the control group and will simply go about your normal gymnastics training.   Some of you will be asked work out with weights for 16 weeks. If you are asked to be in that group, you will replace your normal plyometric training time with weight training. We will ask you to either come to the gym at U.R.I. (the same place you did your testing) to train, or to go to Next Level Fitness Center in Johnston, RI twice a week to work out for one hour. You can choose to train at whichever gym is more convenient to you. One of us will always be there to help you with your training and make sure you are lifting weights properly. For your gymnastics training, you will continue to follow your normal routine.   If you are not asked to do resistance training, you will continue with your normal gymnastics and plyometric training at your regular gym.

At the end of the 16 weeks, we will ask you to come back to the lab at U.R.I and repeat the same tests you did at the beginning of the study.

In order to be part of this study, you have to be a female competitive gymnast with at least a level 7 rank. You also have to be between the ages of 12 and 20, and not have any current injuries.

Risks or discomfort:

Exercise and physical effort can cause soreness or injury from overexertion and/or accident. With strength and jump height testing, some risks exist for muscle strain or pulls of the exercised musculature, muscle spasm, and in extremely rare instances, muscle tears. Some muscle soreness may be experienced 24 to 48 hours after exercise from muscular strength and power testing. That soreness should disappear completely within a few days and have no long-lasting effects.

There are some risks to having your bone density tested because a DEXA uses a similar kind of radiation that an x-ray does. Total radiation exposure for the whole study (one DEXA before and after the study) is almost the same as one and a half chest x-rays or four across-country flights.

There are no known risks for the ultrasound test.

Benefits of this study:

Benefits of this study include potentially decreasing your risk for injury. You will learn how strong you are and how healthy your bones and tendons are. In addition you will be adding important knowledge to your sport and provide you and your coaches' better opportunity to understand and make better training programs for you to follow during your gymnastics season.

Confidentiality:

Your part in this study is confidential. No one else will know if you were in this study and no one else can find out what answers you gave. We will keep all the records for this study and we will be the only people to have access to these records. The documents will be stored in a locked file cabinet in suite 220 in Independence Square on the URI campus. The records will be kept for 7 years and then destroyed.

In case of injury:
Chance of injury while participating in this study is very small, however, due to the strength testing as well as the resistance training and plyometric training groups there is always a small chance of getting hurt. It is not the policy of the University of Rhode Island to compensate subjects in the event that a research procedure results in physical or psychological injury. The University of Rhode Island will, however, make its best effort to refer you to appropriate services, upon request, if injury does occur. You may discuss this with Andy, Justin, or Disa Hatfield. However, if you experience any problems related to this study you should contact your personal physician. In that case you must immediately report what hurts to whoever is working with you at that time. We will then follow the necessary steps to get you taken care of, beginning with contacting any emergency medical service necessary as well as your parents. In the case of an injury that you are not aware of while testing or working out, but you become aware of while at home, school, or practice please contact us to let us know. Our phone number is (401) 874-5183. You may also call the office of the Vice President for Research, 70 Lower College Road, University of Rhode Island, Kingston, Rhode Island, telephone: (401) 874-4328.

Decision to quit or not participate at any time:

You might want to talk this over with your parents before you decide whether or not to be in this study. The decision to be part of this research is up to you. You do not have to participate. We will also ask your parents to give their permission for you to take part in this study, but even if your parents say "yes", you can still decide not to do this. If you do decide to participate, you can always drop out of the study at any time. Whatever you decide will not be held against you in any way. No one will be upset if you don't want to participate or even if you change your mind later and want to stop. If you want to quit the study, just let one of us know or ask one of your parents to call us. Our number is (401) 874-5183.

Your rights as a participant:
If you are not satisfied with the way this study is performed, you may discuss your complaints with Disa Hatfield, Andy Procopio, or Justin Nicoll at (401) 874-5183, anonymously, if you choose. In addition, if you have questions about your rights as a research participant, you may contact the office of the Vice President for Research, 70 Lower College Road, Suite 2, University of Rhode Island, Kingston, Rhode Island, telephone: (401) 874-4328.

Remember, you can ask any questions you may have about this study. If you have a question later that you didn't think of now, you can call one of us at (401) 874-5183 or ask me next time. Would you like to read or hear about this study a second time before you decide?

Signing your name at the bottom of this form means that you have read or listened to what it says and you understand it. Signing this form also means that you agree to participate in this study and your questions have been answered. You and your parents will be given a copy of this form after you have signed it.

______________________________	______________________________
Signature of participant	Signature of Researcher
______________________________	______________________________
Typed/printed Name	Typed/printed Name
____________________	____________________
Date	Date

Appendix III

Participant Number: ___________

(Pre-Post) testing data sheet

Date: ___________ Time: ___________ Competition level: ______

Height: __________cm Weight: __________kg Birth date: ___________ Age: _________

What did you eat and/or drink before you came here?

____

____

DEXA

Time: ______ Tech: ______

Ultrasound

Time: ______ Patella tendon: __________ Achilles tendon: __________ Tech: ______

Force Plate

Trial 1	Trial 2	Trial 3
Peak force: ____________N	Peak force: ____________N	Peak force: ____________N
Peak power: ____________W	Peak power: ____________W	Peak power: ____________W
Jump height: ___________cm	Jump height: ___________cm	Jump height: ___________cm

Notes: ____

____

____

____

____

Initials: _____

Participant Number: ___________

Squat

Warm-Ups: 1. ______________ lbs (5-10 reps @ 50%)
2. ______________ lbs (2-5 reps @ 75%)
3. ______________ lbs (1 rep @ 85-90%)

Attempts: 1. __________ lbs
2. __________ lbs
3. __________ lbs
4. __________ lbs
5. __________ lbs

Bench Press

Warm-Ups: 1. ______________ lbs (5-10 reps @ 50%)
2. ______________ lbs (2-5 reps @ 75%)
3. ______________ lbs (1 rep @ 85-90%)

Attempts: 1. __________ lbs
2. __________ lbs
3. __________ lbs
4. __________ lbs
5. __________ lbs

Notes: ____
____
____
____
____

Initials: _____

Appendix IV

Dynamic warm up

Knee tucks	**X10**
Ankle cradles	**X10**
Lateral squats	**X10**
Spider lunges	**X10**
Spider lunges w/ twist	**X10**
1 leg hip bends	**X10**
Backwards lunge w/ twist	**X10**

*All exercises will be performed alternating sides unless specified

Appendix V

	Day 1	Day 2
	Squat*	Deadlift*
	DB Snatch*	High Pull*
	Stiff Leg Deadlift*	Incline Bench Press
	Seated Row	Pulldown
	Bench Press	Barbell Lunge
	Pull Up	Shoulder Press*
		Upright row

*** represents exercises that will change in weeks 6-10**

	Day 1	**Day 2**
Week		
1	**Pre-testing and familiarization**	
2	Light	Moderate
3	Heavy	Light
4	Moderate	Heavy
5	Light	Moderate
6	Heavy	Light
7	Moderate	Heavy
8	Light	Moderate
9	Heavy	Light
10	Moderate	Heavy
11	Moderate	Heavy
12	**Post-testing**	

Appendix VI

	Light	Moderate	Heavy
Week 1	**Pre-testing and familiarization**		
Weeks 2-6			
Sets	3	3	3
Reps	12	8-10	6-7
Rest (sec)	90	120	120
Total Time (min)	40	48	47
Weeks 7-11			
Sets	3	3	3
Reps	12	6-8	3-5
Rest (sec)	90	150	180
Total Time (min)	40	57	63
Week 12	**Post-testing**		

Appendix VII

Monday
Phase 1

Notes	Exercise	Set Order	Date		Date		Date		Date		Date		Date		Date		Date		Date	
			Wgt.	Reps	Wgt.	Reps	Wgt.	Reps	Wgt.	Reps	Wgt.	Reps	Wgt.	Reps	Wgt.	Reps	Wgt.	Reps	Wgt.	Reps
	1 Deadlift																			
	2 High Pull																			
	3 Incline Bench Press																			
	4 Pulldown																			
	5 Barbell Lunge																			
	6 Shoulder Press																			
	7 Upright Row																			
	8																			
	9																			
	10																			

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Monday
Phase: 2

Notes	Exercise	Set Order	Date		Date		Date		Date		Date		Date		Date		Date		Date	
			Wgt.	Reps	Wgt.	Reps	Wgt.	Reps	Wgt.	Reps	Wgt.	Reps	Wgt.	Reps	Wgt.	Reps	Wgt.	Reps	Wgt.	Reps
	1 Hang Clean																			
	2 Deadlift																			
	3 Bench Press																			
	4 Pulldown																			
	5 Walking DB Lunge																			
	6 DB Snatch																			
	7 Upright Row																			
	8																			
	9																			
	10																			

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Thursday
Phase 1

Notes	Exercise	Set Order	Date		Date		Date		Date		Date		Date		Date		Date		Date	
			Wgt.	Reps	Wgt.	Reps	Wgt.	Reps	Wgt.	Reps	Wgt.	Reps	Wgt.	Reps	Wgt.	Reps	Wgt.	Reps	Wgt.	Reps
	1 Squat																			
	2 DB Snatch																			
	3 SLDL																			
	4 Seated Row																			
	5 Bench Press																			
	6 Pull Up																			
	7																			
	8																			
	9																			
	10																			

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Thursday
Phase 2

Notes	Exercise	Set Order	Date		Date		Date		Date		Date		Date		Date		Date		Date	
			Wgt.	Reps	Wgt.	Reps	Wgt.	Reps	Wgt.	Reps	Wgt.	Reps	Wgt.	Reps	Wgt.	Reps	Wgt.	Reps	Wgt.	Reps
	1 Squat (Jumps on light)																			
	2 Push Press																			
	3 SLDL																			
	4 Seated Row																			
	5 Incline DB Press																			
	6 Pull Up																			
	7																			
	8																			
	9																			
	10																			

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