AN ABSTRACT OF THE THESIS OF

Anastasia M. Kasianchuk for the degree of Master of Science in Exercise and Sport Science presented on December 10, 2010.

Title: Examining the Effects of a Community-Based Physical Activity Program on Moderate to Vigorous Physical Activity and Skeletal Health in Growing Girls

Abstract Approved:

Katherine B. Gunter

Girls on the Run (GOTR) is a community-based running program that encourages social, mental, emotional and physical development in young girls through the process of training for a 5k running event. Previous reports have shown that GOTR has positive effects on self-esteem and dietary behaviors; whether GOTR influences levels of physical activity and bone health outcomes is unknown. Purpose: To determine if participation in GOTR is associated with achieving the recommended moderate to vigorous physical activity (MVPA) of 60 minutes per day for children and positive skeletal development in 8-12 year-old girls.

Methods: Girls (n=31; 9.8±1.4 yrs) were recruited from ten different GOTR Willamette Valley sites to form the intervention group. Girls who did not participate in GOTR or other organized physical activity formed the control group (n=9; 9.6±0.73 yrs). All girls completed a standard health history questionnaire at baseline. Weight, height, and time spent in MVPA were measured at baseline, 3, 6, and 9 months. MVPA was measured by accelerometry over a 7-day period at each time point. Bone mineral content (BMC (g)) and bone structural outcomes; assessed using DXA) and nutrient intakes (assessed using the Youth Adolescent Food Frequency Questionnaire) were evaluated at baseline and 9-months. To evaluate whether GOTR participants were meeting the physical activity minimum recommendations of 60 minutes/day of MVPA, one sample t-tests were applied at each time point evaluating the mean MVPA against a criterion test value of 60 (minutes). To determine whether the mean MVPA varied across time points within the intervention group, and whether there were differences in MVPA between groups across time, we used repeated measures analysis of variance; adjusting for multiple comparisons. To determine baseline differences between groups in BMC and structural outcomes, analysis of covariance (ANCOVA) was used adjusting for age, height, weight, maturation status (years from peak ht. velocity), nutrient intakes and MVPA. The
ANCOVA was repeated at 9-months adding initial bone values to determine differences in BMC and structural outcomes between groups at follow-up. Results: At baseline there were no differences in MVPA between groups. However, GOTR participants had higher BMC (g) at the femoral neck (FN) site compared to controls (mean ± SE; 2.69 ± 0.07 vs. 2.33 ± 0.13; p=0.02) and a larger estimated cross sectional area (cm²) at the narrow neck region of the hip (mean ± SE; 2.01 ± 0.05 vs. 1.76 ± 0.10;p=0.03); there were no baseline differences at any other bone site (p>0.05). At 9-months, GOTR participants had higher FN BMC (p=0.048) and higher trochanteric BMC (p=0.039) compared to controls after adjusting for growth, calcium, vitamin D, activity and initial BMC values. There were no group differences in BMC or structural outcomes at any other bone site (P>0.05). Conclusions: While participating in GOTR, our sample of 8-12 year-old girls had MVPA levels greater than the minimum recommended 60 minutes per day of MVPA, but these levels did not persist after the program ended. After adjusting for growth, maturation, calcium, vitamin D, MVPA, and initial BMC values, we found that GOTR participants exhibited higher FN and trochanteric BMC compared to controls. Thus there appears to be a positive association between participation in GOTR and skeletal development at the hip in growing girls. We expected positive changes in bone would be related to a sustained increase in MVPA. However, this was not the case. Statistical models revealed that MVPA did not explain any of the variability in bone outcomes. It is possible that while the accelerometers captured the general intensity of activities performed, they likely do not sufficiently assess the bone loading nature of activity. In summary, we found that participation in GOTR was associated with higher levels of MVPA and resulted in positive changes in BMC at the hip among young girls participating in the program. Evidence now exists to warrant a broader investigation of this program and its potential to improve health outcomes in young girls.
Examining the Effects of a Community-Based Physical Activity Program on Moderate to Vigorous Physical Activity and Skeletal Health in Growing Girls

by

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Anastasia M. Kasianchuk, Author
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DEDICATION

To my best friend and mom. Thank you for instilling in me a strong work ethic by leading my example. Without your constant support, encouragement, and patience my pursuit of higher education would not be possible. I love you.
CHAPTER 1
INTRODUCTION

Physical inactivity is identified by the Centers for Disease Control and Prevention as a contributor to a variety of chronic diseases including osteoporosis (CDC, 2007). The National Institute of Health defines osteoporosis as “low bone mass and structural deterioration of bone tissue leading to bone fragility and increased risk of fractures” (National Institute of Health, 2007). As of 2005, osteoporosis was considered to be the cause of more than 2 million fractures per year in the United States among male and female adults fifty years of age and older. This equates to approximately $17 billion in direct annual medical costs (Burge et al., 2007). A 50% increase in the number of incident fractures is expected by the year 2025, reaching more than 3 million fractures per year. In turn medical costs are expected to increase to $25.3 billion per year over this same time frame (Burge et al., 2007). Women are three times more likely than men to develop osteoporosis due to a combination of differences in hormones, total lean and fat body mass, and having an overall lower peak bone mass (World Health Organization, 2003). Although old age increases an individual’s risk for developing osteoporosis, poor bone health can be observed at any age (National Institute of Health, 2007), including childhood. Further, childhood may represent the most opportune time to optimize bone health to reduce fracture risk in later life.

During adolescence new bone formation and accumulation leads to increased size and density at a faster rate in comparison to later in life when growing ceases (National Institute of Health, 2007). Ample evidence supports that this period of rapid growth during early adolescence provides a window of opportunity whereby the skeleton is particularly susceptible to external stimuli (Borer, 2005; Karlsson, 2004; Klibanski et al., 2001) and may benefit from targeted interventions to increase bone mass and size (Gunter et al., 2008; McKay et al., 2005). However, in the absence of targeted dietary and physical activity influences, even normally active, typically developing children may be missing an opportunity to optimize skeletal development. For example, in a recent three-year prospective study of children aged 6-16 years at baseline it was noted that children with low bone mass at study entry tended to
have low bone mineral values three years later, independent of normal growth changes in height, weight, and maturation (Kalkwarf et al., 2010). Substantial evidence now exists to support greater peak bone mass development when regular physical activity is participated in early on in life (National Institutes of Health, 2007).

Currently the U.S. Department of Health and Human Services Center for Disease Control and Prevention (CDC, 2008) recommend “children and adolescents participate in at least 60 minutes of moderate intensity physical activity on most days of the week, preferably daily.” Meeting or even exceeding this recommendation may be of particular importance to skeletal health in children prior to and during puberty. Increased physical activity during the period of accelerated growth (puberty) has demonstrated increases in bone mineral accrual as well as bone structure and strength (Bailey, McKay, Mirwald, Crocker, & Faulkner, 1999; Petit et al., 2002). In adolescent females, gains in bone mineral content (BMC) begin to decrease after menarche (World Health Organization, 2003). In both genders, peak bone mineral acquisition is normally attained at the end of the second decade of life with the most rapid growth occurring during adolescence (Rizzoli, Bianchi, Garabédian, McKay, & Moreno, 2010). In females, BMC accrual slows noticeably following menarche (Harel et al., 2007). If optimal peak bone mass is not obtained during these primary years of skeletal growth, individuals are at a greater risk for osteoporosis later in life (National Institute of Health, 2007).

In order to optimally benefit skeletal health through physical activity, children should engage in activities that include sufficiently large weight-bearing forces applied prior to or during early puberty (Gunter, et al., 2008). Weight bearing exercise, such as running and jumping, are not only recommended for the prevention of osteoporosis (National Institute of Health, 2007), but also for the initial attainment of peak bone mass (World Health Organization, 2003). Jumping based interventions in younger populations have elicited positive changes in bone at the hip and lumbar spine; with the greatest benefits observed in pre- and early pubertal populations (Fuchs, Bauer, & Snow, 2001; Fuchs & Snow, 2002; Gunter et al., 2008). These interventions have demonstrated both short and long term positive effects on skeletal growth during childhood, but whether these effects persist into adulthood is still unknown (Gunter et al., 2008). These benefits must be sustained until skeletal maturation to have a long term effect on bone health. Additionally the practicality of adhering to such
jumping interventions beyond the scope of the controlled research environment has yet to be established.

Given the importance of skeletal loading during this critical period of growth, it is necessary to identify other activities that may elicit a positive effect on growing bones. Running is a common activity in both play and recreational environments among young girls and a popular activity for many adults. To our knowledge, the effect of running on skeletal development in growing children has never been reported. There are however several reports on the effects of running on the mature skeleton (Guadalupe-Grau, Fuentes, Guerra, & Calbet, 2009; Kohrt, Bloomfield, Little, Nelson, & Yingling, 2004; Snow-Harter, Bouxsein, Lewis, Carter, & Marcus, 1992). Generally, the effects are mixed with some studies demonstrating an increase in spine BMC through progressive run training (Snow-Harter et al., 1992) to more recent reviews suggesting that the positive effects on bone from running alone are limited and inconclusive (Guadalupe-Grau et al., 2009). Given some studies which have shown running to have a positive (albeit small) affect on the adult skeleton combined with the known differences between the young and mature skeleton regarding bone’s responsiveness to external stimuli, examining the effects of running in this population is worthwhile. Specifically, the growing skeleton is more responsive to applied stimuli during the pre- and early pubertal period (Schoenau & Frost, 2002), thus exploring the effects of running on the younger skeleton during this purported “window of opportunity” makes sense. Further, regular participation in running-based activity may offer a variety of additional health advantages including musculoskeletal and cardiovascular benefits. With the rates of obesity continuing to rise in this population, many interventions aimed at increasing and promoting a lifetime adherence to physical activity have been initiated. Running may be an activity which can positively influence both skeletal health and children’s risk for obesity.

Whether running has a positive influence on skeletal health or not is irrelevant if children are not provided with sufficient opportunity to run. In 2006, 69.3% of elementary schools in the United States were required to offer physical education (PE) as a part of their curriculum. Of these schools, 20.8% allowed students to be exempt from participating for reasons including: high physical competency test score, participation in community service activities, participation in community athletics, and participation in other school activities such as band or chorus (Lee, Burgeson, Fulton, & Spain, 2007). Despite the recommendations for schools to provide physical activity during the school day, few elementary and middle schools
provide daily physical activity to their students. In a study that examined 814 boys and girls (mean age= 9) and the amount of moderate-vigorous physical activity which took place during PE, researchers that only 25 minutes per week on average were spent in moderate to vigorous physical activity (MVPA) (Nader, 2003). In addition, the activities that took place during PE tended to be structured around game play and skill development rather than running-based free-play (Nader, 2003). Although more regulation and policy efforts have been made by schools to offer more physical activity during the school day there is still room for improvement (Lee et al., 2007).

For many students, the period of time after school may represent an opportunity to be more physically active. As such, it may be important to identify effective after school physical activity programs and explore opportunities to increase physical activity during this time (Koplan, Liverman, & Kraak, 2004; Pate et al., 2006). One avenue to pursue through collaborations between schools and community organizations is the provision of alternative physical activity programs to those provided by schools (i.e. competitive team sports). Through the development of positive relationships between schools and community-based providers of after school physical activity programs the potential to provide a greater number and variety of programs, including non-team athletics, exists (Koplan et al., 2004; Pate et al., 2006).

A population of particular concern is adolescent females whose physical activity levels tend to decrease (Trost et al., 2002) at a time when increased physical activity has the greatest potential to optimize bone growth and development (Gunter et al., 2008). Knowing this, it is crucial to identify activities which may optimize musculoskeletal growth and promote long term health through regular physical activity participation in this population.

One activity program that may meet these criteria is Girls on the Run (GOTR). Using experiential learning and physical activity based lessons, GOTR is an international community based running program that trains 8-12 year old girls to complete a 5K running event over the course of a 10-week season. The scripted curriculum uses a variety of activities to encourage social, mental, emotional, and physical development (Barker, 2005). In a pilot study researchers, examined self-esteem, body size satisfaction, and eating attitudes and behaviors in GOTR participants demonstrated significant improvements in these measures compared to baseline after 3-months of participating in the program (RD DeBate & Thompson, 2005). The effects of GOTR on musculoskeletal outcomes however, have never been examined. Further,
whether girls who participate in the program are experiencing beneficial amounts of physical activity has never been quantified. The present research provides valuable information about the effects of a popular, running-based, nation-wide program on physical activity behaviors and skeletal health. Our research study examined whether participation in GOTR is associated with higher levels of physical activity participation and improved skeletal outcomes among growing girls.

Statement of the Problem

The purpose of this study was twofold. Our first aim was to determine whether participation in Girls on the Run (GOTR) had a positive effect on participants’ recorded minutes of MVPA over the 9-month study period. Specifically, we examined whether GOTR participants MVPA levels were similar to the criterion measure of 60 minutes per day and whether the minutes of MVPA recorded changed over the study period. Our second aim was to determine whether participation in GOTR was associated with more optimal bone mass and structure, as measured by dual-energy x-ray absorptiometry (DXA), compared to a control group of similarly aged girls.

Research Hypothesis

The following research hypotheses were tested:

Hypothesis 1: Participants in Girls on the Run will accrue sixty minutes of MVPA per day, meeting the recommended dose, at baseline, 3, 6, and 9 months as measured by accelerometry.

Hypothesis 2: Participants in Girls on the Run will demonstrate enhanced bone mineral content (BMC) of the hip, spine and whole body, improved bone strength and structure of the femoral neck [cross-sectional moment of inertia (CSMI), cross sectional area (CSA) and section modulus (Z)], above baseline and compared to a control group as measured by dual-energy x-ray absorptiometry (DXA) at 9-months.

Operational Definitions:

Moderate to vigorous physical activity (MVPA): MVPA was measured objectively using accelerometers. A subjective self-report instrument was used to note the types of physical activity girls were engaged in during the measurement intervals.
Bone Mass: Bone mass is reported as bone mineral content (BMC, g) and was calculated using DXA technology.

Bone structure and strength: The structure and strength of bone was derived from the DXA measurements using Hip Structural Analysis (HSA) software. Cross-sectional moment of inertia (CSMI), cross-sectional area (CSA), and section modulus (Z) were calculated for the femoral narrow neck and trochanteric regions of the hip.

Assumptions:
The following assumptions were made for the purpose of this study:

1. Participants attended at least 75% of GOTR sessions.
2. Participation during GOTR practice sessions was of similar effort among participants.
3. Self-report of physical activity outside of the GOTR Program was complete and honest among all participants.
4. Accelerometers were worn as instructed during the seven day PA monitoring.
5. Control participants did not participate in any programmed physical activity outside of school based physical education (PE) for the duration of the study.

Delimitations:
The following delimitations were identified for this study:

1. The participants were females, ages 8-12 years old residing in the Linn-Benton County area.
2. The physical activity engaged in while participating in the 10-week GOTR program was dictated by the GOTR curriculum for all intervention participants.
3. The 10-week duration of the program was based on the Oregon State University academic calendar and the already established curriculum.

Limitations:
The following were the limitations of this study:
1. Only 8-12 year old female voluntary non-randomized participants from the *Girls on the Run Willamette Valley* program participated. As such the obtained results are not generalizable to populations not meeting this description.

2. Socioeconomic considerations due to the initial cost of the program may have deterred individuals from participating if the cost was perceived as a burden.

3. The information from the self-report instruments (3-Day Physical Activity Recall and the Youth/Adolescent Food Frequency Questionnaire) was limited to the participants’ and their parent or guardians’ abilities to recall the answers to the questionnaire items.

4. The accelerometers used cannot accurately detect PA levels during activities such as biking when body motion able to be detected by the accelerometer is minimized despite potentially reaching moderate-vigorous levels of PA. Similarly, MVPA during times when the accelerometer was not worn (i.e. athletic competition, swimming) was limited to participant recall.

5. The bone measurements obtained from the DXA were limited by the following: BMC measurements are size-dependent and based on two-dimensional projections of three-dimensional structures which cannot be adjusted for the depth of the bone or scan interpretation difficulties; follow-up measurements are influenced by growth; and the lack of a normative database of measured bone outcomes for this specific population of interest (Sawyer, Bachrach, & Fung, 2007).

6. While the HSA software is useful for bone structure parameter assessment, the assumptions employed for the measurements may not be completely realistic and their validity in young and growing populations has not been extensively assessed to date (Petit et al., 2002).

7. Without limiting the physical activity outside of the *GOTR* program, outcome measurements observed in the *GOTR* participants may not have been solely attributed to the *GOTR* program.

8. Due to efforts to increase our sample size in both groups, *GOTR* participants were recruited during the fall of 2008 and spring of 2009, while a rolling recruitment effort continued for control participants from fall 2008 to summer 2009. As a result baseline and all follow-up measurements did not occur at the same time for each participant.
Significance of the Study:

Bridging the gap between utilizing treatment options for chronic conditions and proactively prescribing preventive modalities such as physical activity requires increased research demonstrating the effectiveness of exercise to prevent chronic conditions in younger populations. Sufficient evidence now exists supporting the recommendation for jumping interventions to effectively improve bone health in children (Fuchs, et al., 2001; Gunter et al., 2008; MacKelvie, Khan, Petit, Janssen, & McKay, 2003; Petit et al., 2002), but the benefits of other types of physical activity are not as well understood. Running, as a component of many games and sporting activities in pre and early pubertal females, deserves greater examination of its effect on bone.

Identifying more types of physical activities that have the potential to optimize bone growth will inform the development of interventions promoting active lifestyles for adolescent populations while helping to prevent osteoporosis later in life. To date, most effective interventions in youth have used jumping as the exercise modality. There is a need to provide a broader exercise prescription to increase bone strength in this population, particularly as public health practitioners strive to promote physically active lifestyles to offset many other chronic conditions. The results of this study support the potential for running-based programs such as GOTR as a viable option through which young girls can accrue sufficient levels of MVPA. Further, the results of this study contribute to the body of knowledge related to the development and implementation of physical activity programs which may promote positive changes in bone mass, shape, and architecture among young girls.
CHAPTER 2

LITERATURE REVIEW

Public Health Burden

Historically, bone health was often overlooked by practitioners until adverse or detrimental effects were experienced by patients, but recent data on the prevalence and cost of osteoporosis and related fractures has made bone health a public health concern. Affecting more than 75 million people in the United States, Japan, and Europe, the World Health Organization (2003) has declared osteoporosis as a worldwide epidemic. In the United States alone, osteoporotic fractures were estimated at about 2 million annually in 2005, equating to nearly $17 billion in national direct expenditures (Burge et al., 2007). Osteoporosis leads to significant morbidity and mortality while being preventable in most cases (Ahmed, Blake, Rymer, & Fogelman, 1997). Pharmacological treatment for osteoporosis in elderly populations is often prescribed for individuals meeting the health qualifications. Despite the investment in these clinical treatments, the incidence of osteoporosis continues to rise.

Physical activity based interventions have been studied extensively as an alternate treatment for the purpose improving bone health in various populations. According to the American College of Sports Medicine position statement on Physical Activity and Bone Health, “weight-bearing physical activity has beneficial effects on bone health across the age spectrum” (Kohrt et al., 2004). While this is well known, exact exercise prescriptions for optimal bone health have yet to be defined appropriately for individual age groups representing different periods of growth and maturation. Lifelong regular physical activity behavior in all individuals has not only been linked to a reduced risk for osteoporosis, but also cardiovascular disease, type II diabetes, and colon and breast cancers (CDC, 2008). Unfortunately recent population trends show that the amount of physical activity participated in declines with age, and it is the time between adolescence and adulthood during which this decline is most often observed (Gordon-Larsen, Nelson, & Popkin, 2004). The declines are dramatic enough that by adolescence, the majority of youth are not getting sufficient activity to meet the minimum recommendations for physical activity, and this decline is seen to continue into adulthood. This is significant in that the time period prior to adolescence is a critical period of growth during which physical activity has been shown to have the greatest
potential to positively influence bone development (Bailey et al., 1999). However, pre-adolescence is also an important time to promote physical activity (Gordon-Larsen et al., 2004). Physical activity interventions in youth can increase physical activity behaviors which will ideally translate to life-long regular physical activity (Dunn et al., 1999).

Many questions still remain and more research is needed to develop population specific interventions for optimal bone health across the lifespan. In order to better investigate this it is imperative to review the literature supporting the ACSM position statement, as well as more recent studies which also look at the long-term effects of physical activity interventions and the subsequent bone health and physical activity behavioral outcomes. This review of literature presents an overview of studies shown to effectively increase activity in youth and a review of research demonstrating that increasing physical activity in during critical periods of growth results in positive bone adaptation responses. Using this knowledge with continued research will help to determine the exact dosage and type of PA which should be implemented in this population to promote ideal bone development.

**Physical Activity and Adolescent Bone Health**

During early puberty the growth of the appendicular skeleton accelerates very quickly. In contrast, of the rapid growth phase of the axial skeleton begins later at a slower rate over a longer growth period (Bass et al., 2002; Macdonald, Kontulainen, Petit, Khan, & McKay, 2008). Nonetheless these growth patterns of the skeleton during this time provide an ideal opportunity for mechanical stimuli such as from physical activity to act favorably on bone growth and development. During the peripubertal period, growth hormone, insulin-like growth factor 1, and sex steroids increase and stimulate osteoblastic stimulation promoting bone growth and turnover for peak bone mineral accrual to be attained (Daly & Petit, 2007).

Early research studies in which researchers examined bone mineral accrual related to physical activity were often cross-sectional in design (Bradney et al., 1998) and tended to recruit participants from athletic populations (Bailey et al., 1999). In a Finnish study of girls 9-16 years old comparing competitive gymnasts and runners to non-athletic controls in, Lehtonen-Veromaa, Mottonen, Svedstrom, et al. (2000) found differences in bone outcomes among the study groups. Specifically, they observed that gymnasts had greater bone mineral density (BMD) and bone mineral content (BMC) than both runners and controls, while runners exhibited greater BMD and BMC than the non-athletic control group. In addition,
observed leisure-time physical activity was greater in the athletic participants than the non-athletic controls. This supports the idea that structured physical activity can translate into or is associated with activity outside of the sport-environment, whereas individuals not participating in such programs may be less likely to exhibit the same motivation to be physically active on a regular basis. The cross-sectional design of this study and use of only self-report instruments to account for physical activity however, require cautious interpretation of the findings. The secondary finding of reduced leisure-time activity among the non-athletes suggests that there is a need to create physical activity programs and opportunities for individuals who are not inclined toward organized athletics or competition. Athletic based programs have been in existence for years and although certainly beneficial, may not appeal to all. Further researching the potential benefits of physical activity programs which are not competition based will provide valuable information regarding the health effects of these programs as well. In turn more programs may be developed providing greater opportunities to optimize overall health and fitness in addition to bone health in targeted populations.

Studies focusing on athletic population contribute to the existing body of knowledge regarding bone changes in athletic populations, but may be confounded by selection-bias and genetic predisposition for higher bone mass (Lehtonen-Veromaa et al., 2000). Further, sport participation often involves very intense physical activity. This selection bias and the variance in the intensity, frequency, and mode of the physical activity in sport specific populations prevents generalizing to normally active individuals, let alone adolescent children (Bradney et al., 1998). Daly et al. (2007) acknowledged the limitations in these study designs in his review of athletes participating in high impact sports, but noted none-the-less that the majority of these studies found that beneficial structural adaptations appeared to occur in loaded limbs. More specifically this response was dependent on maturation, gender, and the type of loading force in that less mature boys and girls had a greater response and weight bearing forces which were moderate-to high-impact and weight bearing induced the greatest changes.

Stear et al. (2003) found that bone mass attained during adolescence correlates to bone health later in life (Stear, Prentice, Jones, & Cole, 2003). While many behavioral factors play a role in the development of optimal bone health, the adaptations to bone structure in adolescents have been documented as a result of changes in mechanical loading generated through physical activity. Moreover, the largest mechanical forces imposed on the bones during loading are mediated by muscle forces, not body weight. These forces not only change
the bone mass, but also its strength and geometry (Daly & Petit, 2007; Janz et al., 2007). While dietary calcium, vitamin D, and hormones may contribute 3-10% of bone strength, greater than 40% of bone strength may be determined by the mechanical loading which is placed on it (Schoenau & Frost, 2002). The mechanostat theory, a functional model of bone development, states that the primary component of bone regulation is the feedback loop between bone deformation and bone strength (Schoenau & Frost, 2002). The mass, size, and architecture of bone tissue responds to loading stimuli within its environment due to its mechanosensitive properties. The extent of these changes appear to be dependent on gender, stage of maturation, and type of load applied (Daly & Petit, 2007). As a homeostatic system, growth and development are critical periods of time when this system is continually forced to respond and adapt to external loading demands (Daly & Petit, 2007; Schoenau & Frost, 2002). Based on this theory, when all else is equal, children who are more physically active should have stronger bones when compared to peers who are less physically active (Bailey et al., 1999). Further, data support that the rapid growth and maturational changes with adolescence make this period of life perhaps the greatest opportunity to positively influence bone development compared to any other time in the lifespan (Bailey et al., 1999).

Using an animal model Warden, Fuchs, Castillo, Nelson, and Turner (2007) found a 7-week exercise intervention to enhance bone quantity, structure, and quality measures in the ulna bones of rapidly growing rats. The intervention performed three days per week for three minutes a day was designed to mimic the jumping protocols which have demonstrated positive skeletal affects on growing children (Fuchs et al., 2001; McKay et al., 2005). More specifically it appeared that the exercise intervention had a greater influence on bone shape as opposed to bone size. After a 92-week detraining period when the rats were approximately two years old, the structural changes induced by the exercise remained, but the bone quantity measures did not. The exercised ulna bones also had greater strength, stiffness, mineralization, and periosteal bone perimeter compared to their non-exercise counterparts. This study used a within-animal design in order to control genetic and environmental factors and measured bone outcomes using both DXA and peripheral quantitative computed tomography (pQCT). Although not generalizable to human populations these results support the benefits of physical activity during growth while at the same time suggesting the changes to bone structure may have potentially greater lifelong benefits to bone than increased quantity measures alone.
Several mechanisms in which bone adapts to increased loading exist. Independently or in combination, the following mechanisms enable bone to adapt to the increasing loads placed on it: bone can be added to the periosteal surface, resorption can be reduced on the endocortical surface, or bone can be added to increase cortical thickness; the architecture of the trabecular area can be altered; and or bone remodeling can be slowed (Daly & Petit, 2007).

In a recent publication (Sardinha, Baptista, & Ekelund, 2008) reported the results of a study where they objectively measured vigorous physical activity relative to BMC at the femoral neck, spine, and whole body in Portuguese boys and girls with an average age of 9.7. They also measured the compressive, bending, and impact strength at the femoral neck. Study participants wore accelerometers for two weekdays and two weekend days. Their results indicated only ~25 minutes of vigorous physical activity may be necessary to stimulate positive bone outcomes at the femoral neck in this population. Of particular interest was the finding that the girls in the study spent significantly more time in light and sedentary activity compared to the boys, and the boys spent significantly more time in MVPA compared to the girls. Not only does this study supports the findings of other studies that the intensity of the physical activity is a critical variable for optimizing bone growth in this population, it also supports other findings that girls of this age are not as active as their male counterparts (Daly & Petit, 2007).

It remains unclear as to whether or not a minimal “activity threshold” for bone growth stimulation exists. Further if such a threshold does exist, whether or not stimulation above and beyond this point will elicit greater gains in BMC is also unknown (Hasselstrom et al., 2007). Further there are measurement issues related to assessing the precise dose of activity required to affect bone changes and other health outcomes. In young children, the majority of their physical activity comes in the form of habitual play which is a multidimensional and complex variable that can be difficult to measure (Sardinha, et al., 2008). It is also not known whether or not habitual play in children provides enough of an osteogenic stimulus for optimal bone growth and development (Hasselstrom, et al., 2007). It known that high to moderate intensity physical activity which is dynamic, multidirectional, intermittent, and rapidly applied can enhance bone growth and development (Daly & Petit, 2007; Sardinha, et al., 2008).
Bone Health and Physical Activity Interventions

Physical activity interventions which incorporate bone loading activities are likely “critical for preventing osteoporosis in mature adults” (McKay & Smith, 2008). Strong evidence exists which shows that children who regularly participate in moderate to high-impact weight bearing activities exhibit greater BMC and bone strength at the corresponding sites where the force was applied. Children who participate in regular physical activity, recreational play, and school-based interventions may demonstrate increased bone mineral accrual if specific bone loading activities are incorporated. The structural impact of these activities on bone however remains a novel area of research (Daly & Petit, 2007).

Bailey et al. (1999) were the first to demonstrate in the University of Saskatchewan Bone Mineral Accrual Study that increased everyday physical activity can result in increased bone mineral accrual in the growing skeleton. The study used a 6-year longitudinal design to evaluate the relationship between everyday physical activity and peak bone mineral accrual in a population of 68 boys and 72 girls going through adolescence. The study design allowed for children of similar maturational stages to be compared. In the Iowa Bone Development Study researchers also employed a longitudinal design to assess the effects of regular physical activity on bone mineral accrual during growth in 127 boys and 162 girls 4-12 years of age (Janz et al., 2007). The Iowa Bone Development Study was one of the first where researchers used accelerometry to objectively measure moderate and vigorous physical activity (MVPA) to relate physical activity behaviors to bone outcomes. They also examined hip structure in addition to BMC. Both the Iowa Bone Development Study and the University of Saskatchewan Bone Mineral Accrual Study results supported that mechanical loading of the skeleton during childhood results in positive effects on bone structure and strength (Bailey, et al., 1999; Janz et al., 2007).

In a 2-year randomized study examining the effects of an exercise program for 8-12 year old boys on bone, researchers observed an increase in BMC accrual and bending strength at the femoral neck (MacKelvie, Petit, Khan, Beck, & McKay, 2004). The study participants took part in a school based circuit jumping intervention which was delivered during regular Physical Education (PE) classes. Jumping was carried out for approximately 12 minutes three times per week and bone changes were reported over the 20-month intervention. Researchers employed hip structure analysis (HSA) in addition to examining DXA outcomes making this among the first studies examining the effect of targeted exercise on bone geometry and bone
strength in this population. The participants’ physical activity outside of the intervention was assessed subjectively in order to control for the effect of exercise outside of the intervention using a modified version of the Physical Activity Questionnaire for Children (PAQ-C). This required participants to recall their physical activity for the previous 7-days. Although easy to administer at a relatively low cost, self-report measurements are subject to the recall bias of the participant (Trost, 2007).

Another study which used accelerometers to measure habitual physical activity, and DXA to measure bone outcomes, also found a dose-response increase in bone mass related to total MVPA. When adjusting for total body lean and fat mass however, the positive association between physical activity and the size of bone showed was diminished. The authors of the study speculated that this may be due to the inverse relationship between physical activity and fat mass (Tobias, Steer, Mattocks, Riddoch, & Ness, 2006).

Specific weight-bearing physical activity prescriptions have not been identified for children (Kohrt et al., 2004), although recent research looking at various types of weight-bearing physical activity have consistently demonstrated a positive influence on bone health. Bradney et al. (1998) compared 20 males with a mean age of 10.4 years who participated in 30 minutes of weight-bearing physical activity three times per week for 32 weeks, to a control group. Weight-bearing activity included basketball, weight training, aerobics, soccer, volleyball, gymnastics, folk, and line dancing incorporated into the schools PE curriculum. The matched control group did not receive any exercise beyond the PE curriculum itself. After the intervention, BMD and BMC increased in both groups, but the increases in the intervention group were nearly twice that of the control group. A limitation to this study is the inability to identify which activity or combination of activities is responsible for the observed positive bone response.

In a study which only looked at jumping, Fuchs et al. (2001) reported that 300 jumps per week for seven months, at ground reaction forces of about eight times body weight, generated improvements in BMC in the femoral neck and lumbar spine in 6-10 year old males and females. This study was randomized, used a specific jumping protocol that was relatively easy to monitor, and accounted for pubertal status. The increases in bone mass were observed at clinically relevant sites of the hip and spine. Of particular relevant interest, follow-up studies conducted in these participants after 7-months (Fuchs & Snow, 2002) and then eight
years of detraining (Gunter et al., 2008), demonstrated evidence of persistent skeletal effects at the femoral neck.

In another jumping intervention that was shorter in duration, researchers found similar results. Male and female participants (mean age= 10 years old) jumped off of a 45cm box, landing on both feet, 25 times per day over 5 consecutive days for 12 weeks (Johannsen, Binkley, Englert, Neiderauer, & Specker, 2003). Even with ground reaction forces of about 4 times body weight, which is at the lower end of the range which bone changes have been observed, changes in total body and distal tibia BMC still occurred. This study accounted for gender and bone size to account for different skeletal loading reactions during various stages of maturity.

Weeks et al. (2007), developed Power PE, a prospective, eight-month randomized, controlled study in which adolescent males and females participated in ten minutes of jumping activities twice per week. The jumping was incorporated into the beginning of PE classes and included: stride jumps, star jumps, lunges, side lunges, skipping, jump-squats, tuck-jumps, and hops. All participants in the jumping group showed significant improvements in femoral neck, trochanter, whole body, and calcaneous bone mass. The improvements observed in the girls in the intervention compared to the controls were specifically at the femoral neck and lumbar spine. This enhanced bone mass in the female jumpers was greater than the differences observed in males. The improvements in bone strength measurements were primarily accounted for by the changes in lean tissue mass that were observed in both males and females. This study again supports the effectiveness of school-based physical activity interventions for the improvement of bone strength parameters. However, it is unknown whether it is an increase in the total amount of physical activity or the specific bone loading nature of the activity which accounted for the positive effects as the researchers failed to report the amount of physical activity that all participants engaged in during the study period.

Haasselstrøm, Karlsson, Grønfeldt, et al.(2007) found in their study of 5-8 year old boys and girls that the total amount of habitual physical activity as well as the amount of vigorous physical activity were associated with BMD values at the calcaneous and distal forearm. Although they did not measure BMC and BMD at the clinically relevant anatomical sites of the hip and spine, physical activity was objectively measured using accelerometers in a large population-based cohort of children from two Copenhagen communities. These results
support the idea that habitual activity as well as targeted high impact activity may be important for bone growth and development especially at this age.

McKay, MacLean, Petit et al. (2005) used a prospective cohort study design to examine the effect of an eight month “Bounce at the Bell” intervention on young boys and girls. During the intervention, students did short duration countermovement jumps three times per day in the classroom. The fifty one children participating in the intervention were compared to a control group of 71 boys and girls who were matched for race, sex, height, and maturity. After the eight month intervention those who participated in the “Bounce the Bell” program demonstrated greater BMC at the proximal femur and adjusted bone area (BA) at the proximal femur and intertrochanteric region compared to controls. In an effort to better define the minimum dose of physical activity which impacts bone development and growth, this study utilized a novel and cost effective intervention compared to those previously implemented. The effects of the intervention on bone were comparable to other studies which examined effects in both girls and boys of similar maturation. Although greater bone gains have been reported, this study demonstrated that even with only a few minutes of countermovement activity per day bone mass can be enhanced in this population (Macdonald et al., 2008). Bone changes were assessed using both DXA to evaluate bone mass and has to evaluate bone structure and strength. The percentage changes in bone structural parameters were favorable in the intervention group compared to the control, but due to the small sample size did not demonstrate a significant effect. The observed changes however were consistent with previous traditional exercise interventions of 8 and 20 months in duration.

Fracture risk cannot adequately be assessed based on the amount of bone material alone. As bone strength is not only related to the amount of bone in a specific area, but also the geometric make up of the bone it is imperative that both are assessed to gain a complete understanding of the bone changes which take place in response to mechanical loading from physical activity (Fricke, Beccard, Semler, & Schoenau, 2010). Based on the results of a studies implementing mechanical loading on rat models, several authors have commented that physical activity may work to increase bone strength by adding BMC to bone in a manner that alters bone’s internal architecture to optimize strength (Bass et al., 2002; McKay & Smith, 2008).

It is important that future studies assess the effects of physical activity on all parameters of bone health in order to strengthen the link between exercise early in life and
optimal bone structure and strength later in life. There are however challenges to measuring
the impact of such programs on bone health in children and adolescents. Many complicated
issues exist when studying exercise effects on bone in growing individuals. For example,
research suggests that exercise may positively affect bone size and strength, but clinically
available DXA methods do not assess these parameters and few researchers possess the
capacity to directly assess structure in children using pQCT. To overcome these limitations
investigators have proposed novel methods to estimate bone strength. Hip structural analysis
(HSA) is one of these techniques which estimates bone structure from DXA measurements
and has proved useful when assessing physical activity interventions (Sawyer et al., 2007).
HSA has capabilities beyond that of DXA to examine the geometric shape and cross-sectional
area at the femoral neck region of the hip. Beck et al. found HSA strength and cross-sectional
area measurements to be similar to those found with experimental and CT images (Beck, Ruff,

With advanced bone measurement technology available with HSA, it is advantageous
to look at structural parameters of bone in addition to BMC in populations still experiencing
bone growth. Few studies in the current literature have used HSA in addition to DXA to
specifically assess bone outcomes in response to community based physical activity programs
in young female participants. Taking advantage of techniques such as HSA will enhance the
limited knowledge which currently exists regarding bone health in female adolescents relative
to their bone health later in life.

**Physical Activity and Bone Health in Adolescent Females**

Osteoporosis effects females at a disproportionally greater rate than males (National
Institute of Health, 2007). As such examining the effects of physical activity in adolescent
girls is of particular interest and several intervention studies have reported the specific effects
of targeted physical activity in young female populations (Macdonald et al., 2008; MacKelvie
et al., 2003; Morris, Naughton, Gibbs, Carlson, & Wark, 1997; Petit et al., 2002). Petit et al.
(2002) looked at 70 prepubertal and 107 early pubertal girls randomly assigned to an exercise
intervention or control group (Petit et al., 2002) in order to determine the potential influences
of a jumping protocol on bone mass and structure. The intervention included a variety of
different types of jumps that girls performed for about 10 minutes during regularly scheduled
PE classes twice per week. Over the 7-month intervention period, the prepubertal girls did not
show any significant differences compared to the control group for the bone variables of interest. The early pubertal group however, showed significantly greater gains than the control group at the femoral neck and intertrochanteric sites. This study suggests that a school based jumping intervention can result in maturity and site-specific changes in bone mass and structure in girls during early puberty. The adaptations observed in bone due to mechanical loading depend on the skeletal site, the specific structural variable being measured, and the maturity of the participants.

Macdonald et al. (2008) observed similar skeletal adaptations to those of Petit et al (2002) in femoral neck bending strength among girls participating in the Action Schools! BC program (Macdonald et al., 2008). The Action Schools! BC intervention took place over 20 months and included a jumping protocol with lower intensity of bone loading. Despite the lower intensity, the adaptations were similar, suggesting an additive effect given that the intervention was twice the length of that delivered by Petit et al. (2002). Additionally, the majority of these girls were at an early pubertal maturation stage, which further supports that the maturity of the participants plays a role in the skeletal adaptations which take place. Specifically the bone structural changes found were a greater femoral neck cross-sectional area (CSA), greater distribution of the bone material from the center of mass (cross-sectional moment of inertia; CSMI), and a greater section modulus (Z). Physical activity was found to be a significant independent predictor of the positive changes in CSA and Z variables (Macdonald et al., 2008). This study demonstrated that a simple school based program can promote bone mass gains and favorable structural changes in its participants similar to those observed in other interventions which required more time and greater intensity.

MacKelvie et al (2003) employed a randomized controlled study design to examine the effects of jumping activities in 32 girls in an intervention group compared to 43 girls in a control group (MacKelvie et al., 2003). The intervention was facilitated by PE instructors during PE classes and consisted of a circuit-training model that incorporated five different plyometric jumping activities that children did for 10-12 minutes three times per week. Researchers observed increases in BMC at the lumbar spine of 3.7% and 4.6% at the femoral neck over the 20-month intervention. This simple and safe program was effective for enhancing bone mineral accrual during early childhood.

Morris, Naughton, Gibbs, Carlson, and Wark (1997) looked at the effect of a variety of structured work-outs including a 20-station weight bearing strength-building circuit in 9-10
year old premenarcheal females (Morris et al., 1997). The increased magnitude of mechanical loading on the bone produced a significant difference in bone mineral accrual in those who participated in the 10-month program compared to those who did not participate. This was a non-randomized controlled study which examined bone mineral response among other factors in a sample population of 71 females. Significant changes were also noted in body composition and strength. The effect of the exercise intervention was associated with increased BMC accrual independent of change in height and total body mass due to growth and maturation. In the control group the only independent predictor of bone mass change was increased fat mass. Although the bone health outcomes found in this study were encouraging, researchers did not account for activity outside of the intervention program using valid and reliable measurement techniques. Physical activity in the intervention group was assessed twice subjectively using a self-report questionnaire developed by Godin and Shepard (Godin & Shepard, 1985) while physical activity in the control group was measured using a different unspecified physical activity diary without reliability and validity data to support its use. Different types of physical activity elicit varying bone responses and in order to have confidence that bone benefits observed during an intervention are not related to physical activity outside of the intervention, reliable assessment of this activity is essential. Measurement issues aside, more research is needed to for a greater understanding of the specific effects of different activities on bone in peripubertal girls (Lehtonen-Veromaa et al., 2000).

Using data from the University of Saskatchewan’s Pediatric Bone Mineral Accrual Study Baxter-Jones et al. (2008) performed an analysis which prospectively and longitudinal examined the influence of physical activity on bone outcomes during childhood, adolescence, and into young adulthood (Baxter-Jones, Kontulainen, Faulkner, & Bailey, 2008). Females who were significantly more active during adulthood were found to have been more active during childhood as well. Despite no differences in female activity observed between adolescence and young adulthood, female adolescents who demonstrated a greater activity level did show on average, greater BMC values at the total hip (8.6%) and femoral neck (9.5%) when compared to their inactive counterparts. Total hip and femoral neck BMC values in young adult females who were active during adolescence were observed to be 9% and 10% greater respectively compared to those who were inactive during adolescence. BMC values were adjusted for age, maturity age, height, weight, physical activity, calcium intake, and
BMC after one year of reaching peak height velocity. These results suggest the benefits accrued from increased physical activity during peak bone growth during childhood can continue into young adulthood. Also of interest from this study was that activity levels during adolescence for females were positively correlated with those in adulthood. This suggests adolescence may be an ideal time for physical activity promotion generally and for osteoporosis prevention specifically. With the study design and large sample size, and sophisticated analytical approach, the findings of this study contribute significantly to this area of research. It must be noted however, that as an observational study there are limitations related to selection bias, uncontrolled factors, and reverse causality. One limitation was in the measurement of physical activity. Given the large sample size physical activity was assessed subjectively using the Physical Activity Questionnaire for Children (PAQ-C), Physical Activity Questionnaire for Adolescents (PAQ-A), and the Physical Activity Questionnaire for Adults (PAQ-AD). An objective measure of physical activity would have provided stronger support for the observed results.

There are few studies which specifically examine the effects of physical activity programs targeting growing girls and as such, strong evidence of an effect of these programs is lacking (van Sluijs, McMinn, & Griffin, 2007). Therefore a need exists for more well designed studies examining the effects of physical activity programs to both promote increased physical activity behaviors and subsequent changes in bone among young girls.

**Physical Activity Programs and Physical Activity Behavior**

Physical activity levels in younger populations decrease dramatically beginning in adolescence (Gordon-Larsen, et al., 2004; CDC, 1999). As this appears to be a critical point for establishing the foundation for optimal bone health throughout life, greater emphasis should be placed on the initial acquisition of optimal bone size, geometry, and mass prior to adolescence when activity levels drop (Sawyer et al., 2007). However, the benefits to bone gained through physical activity early in life must be long lasting in order to influence bone health into adulthood (Burrows, 2007). As such there is a need to promote long-term adherence to physical activity among girls and a need for long-term prospective studies to assess adherence and the potential persistent benefits of physical activity undertaken in childhood on the mature skeleton.
Price et al. (2008) examined the relationships between weight-bearing physical activity and girls’ perceptions about physical activity in a sample of adolescent girls (Price et al., 2008). Researchers reported a significant association between weight-bearing physical activity and girls’ perceptions of their friends’ physical activity and the perceived availability of physical activity based after school programs. Having social support from friends who are physically active was an important correlate for girls participating in weight-bearing physical activity themselves. From this study it was suggested that parental encouragement for participation in weight-bearing physical activity in conjunction with the opportunity to be active with peers may be an effective approach for increased and long-term participation in weight-bearing physical activity. Price et al. (2008) hypothesized that girls who are more physically active believe others should spend more time being physically active as well (Price et al., 2008). Increased weight-bearing physical activity in female adolescents is dependent on both the social and physical environments which enable physical activity to take place (Price et al., 2008). Therefore increasing social support and providing sufficient opportunities to be active may be effective ways to increase weight-bearing physical activity in this population. To date, there are no published reports to suggest that programs developed to increase physical activity behaviors specifically among young girls translates to improvement in skeletal health in this population.

The Trial of Activity for Adolescent Girls (TAAG) was the first intervention to link schools with outside communities in order to provide greater physical activity opportunities for its middle school aged female participants (Young et al., 2008). Process evaluation results supported both feasibility and acceptability of the TAAG program among its participants (Young et al., 2008). Although this intervention was able to achieve a high reach within the PE and health education classes through which the program took place in school, the reach for promotional events and after school programs was much lower due to competing priorities (Young et al., 2008). This suggests a need to make programs available during discretionary time outside of school particularly appealing and accessible.

In their review of controlled trials van Sluijs, McMinn, and Griffin (2007) found only 12 of the 33 studies looking at interventions to increase physical activity among children used an objective measure of physical activity. Additionally most of these studies only assessed physical activity during the intervention itself failing to examine the impact of the intervention on physical activity outside of the program, or the persistent effects of the program on
physical activity behaviors once the program was over. Most physical activity programs only provide an allotted amount of physical activity to its participants. For example, if a program is offered during PE, the direct effects will happen during this time, but carry-over effects may be observed outside of the program. However, if researchers do not measure physical activity outside of the intervention, a potential larger impact of the intervention cannot be observed. However, in this particular review only 5 of the 33 studies did this.

**Community Based Physical Activity Programs**

In a review of controlled physical activity trials van Sluijs, McMinn, and Griffin (2007) identified 57 intervention studies intended to promote physical activity. Of these, 33 were aimed at children. Only 14 of the 33 studies targeting children had a community or family component, with the majority being school based interventions. Some of the school based interventions also included existing community physical activity events. From these studies alone there was not a substantial amount of evidence to support an effect of participation in community-based physical activity programs on children’s physical activity behaviors. Further, most of these studies were not randomized and had small sample sizes (van Sluijs et al., 2007).

**Running Programs in Youth**

Although running programs for children exist, few are gender specific or delivered as a community-based after school program. Of particular interest was that none of the running specific programs found for this age group measured bone changes as an outcome.

Xiang, McBride, and Breune (2003) examined the affects of an elementary PE running program, but in relation to parental beliefs and motivation for physical activity in children. They reported that parental beliefs in their child’s motivation played an important role in positive participation in the running program. The SPARK (Sports, Play, and Active Recreation for Kids) program provides an extensive activity curriculum for its providers, however this is a school based program which uses a variety of activities, not only running, to increase time spent in MVPA among male and female elementary students (McKenzie, Sallis, & Rosengard, 2009). A similar program is available for Middle School students: M-SPAN (Middle School Physical Activity and Nutrition). Following a similar format as SPARK children participating in, M-SPAN demonstrated increased MVPA during PE. The girls in
this study however, did not demonstrate the same levels of increase as the boys, suggesting that an alternative approach may be needed to effectively increase physical activity levels in adolescent girls (McKenzie, Sallis, Prochaska, Conway, & Rosengard, 2004).

The Robert Wood Johnson Foundation has supported two running programs for middle and high school students: Students Run LA and Students Run Philly Style (Brodeur, 2005). Although the successes of these programs have been documented in the media, the outcomes have not been thoroughly quantified through well designed research studies (Brodeur, 2005). Hansen-Turton and Johns (2005) presented an abstract at the American Public Health Association 2005 meeting about the consistency of the program’s objectives with the National Nursing Centers Consortium (NNCC), which facilitated the program. The objectives of the Students Run Philly Style Program aligned with those of the NNCC related to promoting increased health practices among at-risk youth through neighborhood community-based programs (Hansen-Turton & Johns, 2005). However whether or not children who participated were doing more activity as a result of their participation and the potential effects of participation on health outcomes is unknown.

It appears that exploiting the link between school environments and other community-based programs may be a feasible approach to increasing physical activity among young girls to potentially generate positive health outcomes. More research is needed however, to better evaluate the relationship between participation in community-based programs and the outcome measure of physical activity behavior in pre-adolescent girls.

**Girls on the Run (GOTR)**

*Girls on the Run (GOTR)* is a national program with a specific curriculum that uses a 5K running training program to promote physical activity as well as emotional, social, and mental health in 8-12 year old girls (Barker, 2005). To date, few published studies have evaluated the effects of this program on the health behaviors, such as increased physical activity, which are expected to be affected within this target population. Additionally, there are no studies which have evaluated physical health outcome measures such as BMC and bone structure related to the physical activity dosage girls experience as participants in *GOTR*. Thus far, published studies have only evaluated the impact of this program on the emotional, social, and mental outcomes of participation.
GOTR cultivates an environment for positive successful experiences, increasing the likelihood participants will continue to engage in the activity in which mastery was achieved (Waldron, 2007). In a study qualitative study of older girls who participated in Girls on Track (GOT), a program similar to Girls on the Run, but for middle school aged girls, participants revealed that they experienced a supportive and cooperative environment while participating in the program. Involvement in a positive peer group may have also contributed to increased peer-acceptance and individual social skills (Waldron, 2007). Interviews also revealed that the girls perceived improvement in their overall running ability as well as increased enjoyment for running as physical activity. Three of the interviewed participants also stated that their experience with GOT made them want to participate in additional organized physical activity. In a similar study of younger girls participating in GOTR, DeBate et al. (2007) found increased levels of commitment to regular physical activity as well as a decrease in negative attitudes toward physical activity participation among GOTR participants.

Although informative, these studies had a number of significant methodological limitations. In the study by Waldron et al. (2007) the small sample size decreased researchers’ abilities to detect statistically significant differences among the quantitative measures. In addition pre and post test measurements taken over only 7 weeks may not have allowed for meaningful and measurable changes to occur (Waldron, 2007). Although DeBate et al. (2007) used a larger sample, the study results were based on a qualitative survey and a pretest-posttest experimental design without a control group. The surveys were only administered at the beginning and end of the program failing to examine the long term impact on physical activity behaviors (DeBate, Zhang, & Thompson, 2007). Follow-up measurements of physical behavior are necessary to adequately assess if a lasting effect of GOTR participation exists. Further, neither of these studies assessed any physical health parameters. Understanding the physical as well as behavioral benefits of the program may support broader dissemination, particularly if the benefits are significant. With 150 programs throughout the United States and Canada (Girls on the Run International, 2008) the program has great potential to benefit large numbers of young girls.

Summary

In order to prevent osteoporosis later in life, efforts must be made to make sure adolescents reach their full potential peak bone mass (Cromer & Harel, 2000). It has been
established that positive bone health outcomes can be achieved by implementing weight-bearing physical activity during these critical growth years. The exact mode, frequency, intensity and duration of weight-bearing physical activity specifically for adolescent females has yet to be clearly defined. Interventions aimed at adolescent females are particularly advantageous since females are at a greater risk for developing osteoporosis. Structured programs designed to take place in a PE setting have been effective, but there is a need to assess the effects of other programs which take place in more natural social environments. In addition, the effects on bone health and development of other forms of activity aside from jumping should be measured. We know that jumping as a high impact activity has positive effects on bone, but there is no evidence to suggest that participants continue to participate in such activities beyond the venues where these programs are delivered. A physical activity intervention which incorporates running while encouraging self-esteem and self-awareness with other females of the same age has great potential to promote physical activity habits beyond the setting of *GOTR*. To our knowledge there are no published studies that have examined both skeletal health and physical activity behavioral outcomes related to a community-based physical activity intervention in growing girls and no published studies examining the effects of participation in Girls on the Run on skeletal health. Thus our study is novel and contributes to this area of research. The results of our study may help to further bridge the gap between identifying and implementing physical activity interventions and programs to optimize bone health and promote positive physical activity behaviors in adolescent females currently, as well as into the future.
CHAPTER 3

METHODS

Experimental Design

An extended non-equivalent control group design was used for this study. The experimental group comprised of self-selected participants in GOTR; the control group included similarly aged girls who were not enrolled in GOTR and without any plans to participate in an organized sport over the nine month duration of the study. Anthropometrics and objective and subjective 7-day physical activity assessment were taken at baseline, 3, 6, and 9 months for both groups. Bone mineral content and bone structure was assessed at baseline and 9 months. Participants in the intervention group were required to participate in GOTR for at least one complete 10-week session. Control participants were retained in the study if they did not participate in an organized physical activity program during the 9-month surveillance period. All eligible study participants were asked to come back for follow-up visits at 3, 6 and 9 months. Following both the control and intervention groups allowed for examining the influence of group membership on skeletal outcomes and MVPA levels.

Participants

A convenience sample of forty-five 8-12 year old girls residing in the Linn-Benton county area was initially enrolled in the study. All interested girls meeting inclusion criteria were invited to participate regardless of race or ethnicity. Participation was voluntary. Thirty-three participants came from seven different GOTR Willamette Valley sites over the course of the Fall 2008 and Spring 2009 seasons. Participants were recruited into the study for 9-months from the date of entry. Thus participants who entered the study in September 2008 were followed through June 2009 and participants who began in March of 2009 were followed through November of 2009. Participants were required to attend at least 75% of the GOTR sessions (15 out of 20). Adherence to GOTR for each participant was monitored based on attendance records kept by the coaches. Girls not attending 75% of the total sessions were excluded. Intervention group recruitment took place prior to or upon registering for GOTR via 1) information given with registration, 2) distributed flyers, 3) informational meetings held at
the schools and GOTR practice sessions, 4) word of mouth from the GOTR coaches and staff, and 5) through phone calls to the parents of the GOTR participants informing them about the study.

The remaining 12 participants formed the control group. These participants were instructed to continue their daily routines as normal for the duration of the study. Participants were excluded if they intended to or actually began a sport or organized physical activity program while enrolled in the study. Control participants were recruited from the Corvallis community via 1) flyers posted on the Oregon State University (OSU) campus, the Corvallis Boys and Girls Club, and local churches, 2) information provided at elementary and middle school events and open houses, 3) through KidSpirit upon registering for non-physical activity based programs, 4) informative presentations in physical education classes and parent-teacher association meetings, 5) through a local press release, and 6) word of mouth. Recruitment for controls was done on a rolling basis until July 2009 when it was determined that all feasible recruitment options had been exhausted based on the resources available to the researchers at the time.

Data Collection Procedures

After enrolling in the study, participants visited the OSU Bone Research Lab (BRL) at pre-scheduled times. Information about the details of the study including: purpose, measurements to be obtained, and risks and benefits to the participant were provided for both the participant and their parent or guardian prior to baseline testing. Informed consent was obtained from parents or guardians and informed assent was obtained from children who elected to participate. All informed consent documents as well as the study protocol were reviewed and approved by the Oregon State University Institutional Review Board.

All of the same measurements were taken for control and GOTR participants. During the first visit, each participant, along with their parent or guardian, completed the parental informed consent, child assent, health history questionnaire (HHQ), and the Youth/Adolescent Food Frequency Questionnaire (YAQ). Baseline anthropometric measurements (standing height, seated height, and weight) and Dual X-Ray Absorptiometry (DXA) scans at the left femoral neck, lumbar spine, and full body were taken. All questionnaires with the exception of the YAQ, along with height and weight measurements were repeated at the 3, 6, and 9-
month visits. Bone scans and the YAQ were repeated at the 9-month visit only. Detailed description of the measures and protocols are described below.

**Measured Variables**

**Anthropometrics**

Standing and seated height were measured using a standard wall mounted stadiometer. Participants stood upright against the stadiometer in their stocking feet and measurements were taken to the nearest 0.1 cm. Seated height was measured by having the participants sit upright against the stadiometer on a previously measured 50.5 cm box. For both standing and seated height the mean of two separate measurements was reported. If the two initial measurements differed by more than 0.5 centimeters a third measurement was taken and the two measurements which were separated by 0.5 centimeters or less were averaged. Body weight was measured by having participants stand on a digital scale which was calibrated prior to each visit. Participants, in stocking feet and lightly dressed, were weighed twice to the nearest 0.1 kg and their weight was recorded as the average of the two measurements. If the two initial measurements differed by more than 0.5 kg a third measurement was taken and the average of the two measurements separated by 0.5 kg or less was reported.

**Bone and Body Composition Outcome Measurements**

**Dual-Energy X-Ray Absorptiometry (DXA)**

Bone mineral content (BMC; g) of the hip, L1-L4 lumbar spine, and whole body was evaluated using DXA (Hologic QDR 4500A; Hologic Inc., Waltham, MA, USA). Whole body scans were performed to assess body composition. All bone measurement scans and analyses were performed based on standardized procedures (Hologic, 2000). According to Sawyer et al. (Sawyer et al., 2007) DXA continues to be the primary bone densitometry tool used for pediatric research and clinical bone assessments. DXA uses high and low energy x-rays through the body to distinguish between soft tissue and bone. The x-rayed bone content is quantified by subtracting the amount of soft tissue from the combination of soft tissue and bone (Sawyer et al., 2007).

**Hip Structural Analysis (HSA)**
Hip Structural Analysis (HSA), introduced by Beck and colleagues (Beck et al., 1990), derives the bone geometry of the femoral neck from DXA bone mineral images (Sawyer et al., 2007). Hip structural analysis (HSA) was performed on hip DXA scans to evaluate cross sectional area (CSA, cm$^2$), cross sectional moment of inertia (CSMI, cm$^4$) and section modulus (Z, cm$^3$) at the intertrochanteric (IT) and narrow neck (NN) regions of the proximal femur. The HSA program utilizes two-dimensional data from DXA scans to estimate three-dimensional structural outcomes and can provide additional information about skeletal strength beyond that given by measurements of mass alone.

**DXA Precision**

To evaluate the precision of bone mass and structural outcomes, participants were scanned twice at the hip and spine during their first visit. In-house operator precision for hip and spine BMC measures are presented as the coefficient of variation (CV) and were calculated at 1.8% and 1.0% respectively in this sample of 8-12 year old girls. Precision values for femoral neck and intertrochanter BMC were calculated at 1.8% and 4.9%, respectively while precision for hip structure parameters ranged from 3.1% (NN CSA) to 7.7% (NN CSMI). In order to minimize the radiation exposure to the participants during data collection, positioning devices were used to increase measurement precision. For the femoral neck measurement, an apparatus held the left leg internally rotated at 30° for the lumbar measurement, another apparatus held knees at 90° of flexion while lying supine. A system phantom was scanned daily for each day of data collection to maintain quality control.

**Physical Activity Assessment**

**Objective (Accelerometry)**

The Actigraph 7164 (Shalimar, FL) accelerometer was used to objectively assess physical activity. The Actigraph 7164 is a uniaxial accelerometer designed to detect vertical accelerations ranging from 0.05-2.0 G’s with frequency response of 0.25-2.50 Hz (Freedson, Pober, & Janz, 2005). The acceleration signal was digitized at a rate of 10 Hz, filtered, rectified, and integrated over a user specified time interval called an epoch. Epoch measurements of 30-seconds were used to assess the intermittent activity patterns in the participants. The Actigraph 7164 was used to measure physical activity over seven days (Freedson et al., 2005) at baseline, 3, 6, and 9 months. Seven days of PA assessment allowed
for weekend versus weekday physical activity to be observed providing a more reliable estimation of usual physical activity (Trost, McIver, & Pate, 2005).

At each visit the accelerometer was positioned on each participant by a research assistant on the right midaxilla line at the level of the iliac crest and secured with an elastic belt. Both the participant and parent were instructed on how to secure and care for the accelerometer on their own prior to leaving the laboratory. Accelerometers were initialized as specified by the manufacturer prior to being given to each participant with the start time beginning at 5:00:00 am of the next full 24-hour period. The serial identification number assigned to each Actigraph was recorded in each participant’s file.

**Data Reduction**

After the seven-day monitoring period, participants returned to the lab and the data from the units was downloaded, stored, and reduced using a customized software program. This software program was then used to determine the daily time spent in sedentary, light, moderate, vigorous, and moderate-to-vigorous physical activity (Trost, Rosenkranz, & Dzewaltowski, 2008). The age specific count cut-points corresponding to the aforementioned intensity levels were derived from the prediction equation developed by Freedson et al. (Freedson, et al., 2005; Freedson, EdwardSiraad, John, 1998). Non-wear time over the seven day monitoring period was determined by summing consecutive zero-counts which lasted for ten minutes or longer. For a monitoring day to be considered valid, wear time must have been equal to or greater than 600 minutes per day (Trost et al., 2008).

Specific verbal and written instructions were given to both the participants and their parents about the use and care of the accelerometer. They were instructed to wear the device during waking hours for seven consecutive days while also completing an accelerometer wear and non-wear log. The log was used for the entire 7-day period for participants to note the time when the accelerometer was worn and when it was not. For wear time they were instructed to simply check the column which corresponded to the each hour of the day the activity monitor was worn. All non-wear time was estimated using data reduction by summing consecutive zero counts which occur for longer than sixty minutes. When the accelerometer was not worn participants were instructed to record the activity done during that time. Such activities primarily included swimming, bathing, and sleeping. There were occasions however, such as during a soccer game, dance or gymnastics practice when
participants reported not being allowed to wear the activity monitor either for safety concerns or rules of the sport. There were also other occasions when the participants simply forgot to wear the monitor and recorded the activities they did during that time based on recall. To account for non-wear time, an adjusted MVPA variable was created. Adjusted MVPA was determined by integrating one third of the amount of time recorded, up to 60 minutes, of the activities which occurred during the non-wear time to the objectively measured MVPA. Analyses of MVPA over time and relative to bone outcomes were performed using both adjusted and unadjusted MVPA values and reported in the results.

*Subjective Physical Activity Assessment (Self-Report)*

Self reported physical activity was assessed using the Three Day Physical Activity Recall (3DPAR), an extension of the Previous Day Physical Activity Record (PDPAR) (Pate, Ross, Dowda, Trost, & Sirard, 2003). Participants were instructed to complete the 3DPAR for only three of the 7 days of accelerometer wear time (Monday, Tuesday, and Sunday). These days remained the same for all follow-up visits.

Self reported data was collected to provide information on the specific types of physical activity the participants did in addition to the objective data related to the time and intensity of activity provided by the accelerometers. Each recall day, beginning with the most recent day, was broken into 30-minute time blocks beginning with morning and ending in the evening. A list of 55 activities was provided and grouped into the following categories: eating, sleeping/bathing, work/school, transportation, spare time, physical activities, and sports. Participants indicated in each 30-minute time block the primary activity they participated in. This instrument is specifically designed for the cognitive abilities of children and adolescents and was found to be valid and reliable in a population of 13-16 year old females when compared to 7-day accelerometry (Pate et al., 2003).

*Questionnaires*

*Health History (HHQ)*

Each parent or guardian completed a HHQ during the first visit for the participant. Ethnicity, race, osteoporosis risk factors, and menstrual status were included on the HHQ. The HHQ was reviewed by the researcher to evaluate any potential bone-altering conditions or medication use and to identify any injuries which occurred over the study period that may
have affected physical activity behavior. The HHQ was reviewed at each time point by the participant and their parent. Any changes were noted.

Youth/Adolescent Food Frequency Questionnaire (YAQ)

With the help of their parents or guardians participants completed the Youth/Adolescent Food Frequency Questionnaire (YAQ) during the baseline visit and 9-month follow-up. This is a self-administered, computer-scored, 151-food item and frequency tool designed for children ages 9-18. The questionnaire took approximately 30 minutes to complete. Research assistants helped with the questionnaire providing visual aids and descriptions for different foods and serving sizes relative to the questions being asked. The YAQ has been tested qualitatively and quantitatively on this age group and found to be reliable and valid. Data of relevance from the YAQ were total calcium and vitamin D intakes; nutrients known to influence skeletal growth and development.

Maturity Assessment

Maturation and growth of each participant was quantified by determining participants’ growth relative to peak height velocity (PHV). PHV is a commonly used biological parameter in growth studies which allows participants to be aligned at comparable biological rather than chronological ages (Baxter-Jones, Eisenmann, & Sherar, 2005; Forwood et al., 2006; Mirwald, Baxter-Jones, Bailey, & Beunen, 2002). In the present paper, all bone measurements are considered in terms of time before and after PHV (Baxter-Jones, et al., 2005; Baxter-Jones, Mirwald, McKay, & Bailey, 2003; Malina, 1978; Mirwald et al., 2002). Since the majority of participants had yet to reach PHV (average age of PHV is 12 in girls) by the end of the study, age of attainment of PHV was estimated by applying gender specific anthropometric prediction equations (Mirwald et al., 2002). These equations use markers of somatic growth to predict how far a child is, in years, from reaching PHV. The equations use growth characteristics incorporating current standing height and sitting height parameters, adjusted for age and weight, to predict when peak height velocity will occur (maturation offset). The prediction equation was applied at each measurement occasion.

Intervention: Girls on the Run Program
The already established *GOTR* curriculum uses physical activity to facilitate lessons designed to boost self-esteem and encourage emotional, social, mental, and physical development in young girls (Barker, 2005). The program was run by Oregon State University *KidSpirit* Staff and local elementary and middle schools provided the outdoor sites for the program to take place. Each session was 75 minutes in duration on two non-consecutive days during the week for 10 weeks. Each *GOTR* season roughly coincided with the OSU academic year. All sessions were led and supervised by a head coach and at least one assistant coach. Both head and assistant coaches were trained by the *GOTR* program director at OSU.

The amount of physical activity outlined for each practice session gradually increased over the course of the season to prepare each participant to complete a 5 kilometer race event at the end of the season. The structure of the curriculum was set up so time spent participating in physical activity began with about 15 minutes during the first week and progressively increased to 60 minutes by the conclusion of the program (Barker, 2005). The majority of the running activity took place over a measured distance (perimeter of a field or track). Lap counters were used for the girls to keep track of the distance they covered during each session. Coaches were encouraged to document the number of laps completed by each girl as well as the approximate minutes of PA for each session as a form of process evaluation. A sample lesson is included in the appendices.

**Process Evaluation Methods**

A process evaluation was conducted to assess the feasibility of the *GOTR* program. Factors taken into account for this included: the number of days the program was offered within the given season, the approximate duration of each practice session, what was done during each practice session, and the percent of attended sessions by each participant. Problems which impeded the program implementation and other perceived barriers were also noted.

**Data Analyses**

Descriptive analyses were performed using SPSS software version 17.0 for Windows (PASW Inc.). Values are reported as means (+/- SD), a level of significance of p<0.05 was used, and all statistical tests were two-tailed. Baseline independent sample t-tests were run on all descriptive and physical activity variables.
To evaluate baseline differences in BMC and bone structure [cross sectional area (CSA, cm²), cross sectional moment of inertia (CSMI, cm⁴), section modulus (Z, cm³)] between groups, analysis of covariance (ANCOVA) was used with baseline age, height, weight, calcium, vitamin D and maturation status (maturity offset; reported as years from peak height velocity) included as covariates. Each model included condition (GOTR vs. controls) as the grouping variable [Table 2; means (SE)]. To evaluate group differences in BMC and bone structural outcomes at the 9-month follow-up, ANCOVA was repeated with follow-up age, height, weight, calcium, vitamin D, MVPA (averaged across all measured time points), maturation status, and initial (baseline) bone values included as covariates [Table 3; means (SE)].

To evaluate whether GOTR participants were meeting the physical activity minimum recommendations of 60 minutes/day of MVPA, one sample t-tests were applied at each time point evaluating the mean MVPA against a criterion test value of 60 (minutes). The Bonferroni method was applied to adjust for multiple comparisons. As such the alpha level was set at p=0.0125 for this analysis. To determine whether the mean MVPA varied across time points within the intervention group, and whether there were differences in MVPA between groups across time, we used repeated measures analysis of variance; adjusting for multiple comparisons.
CHAPTER 4

RESULTS

Thirty-one out of 33 recruited GOTR participants and 9 out of the 12 recruited control participants completed the study. Two GOTR participants did not complete the study due to lack of interest prior to the 3-month follow-up visit. The three control participants voluntarily withdrew from the study, because one participant no longer met the inclusion criteria by electing to participate in an organized physical activity; another participant had to withdraw due to personal family issues as cited by her parents; and the third participant withdrew due to lack of interest. Analyses were performed on intervention (n=31) and control (n=9) participants who completed all study measurements at baseline and follow-up. At baseline there were no differences in chronological age, maturation status, weight, height, or body composition between GOTR participants and controls (p>0.05, Table 1). Baseline t-tests also revealed no differences between groups in MVPA (p>0.05). Baseline ANCOVA results showed no differences in baseline BMC at the total hip, intertrochanter and spine (p>0.05). However, there were differences between groups at the femoral neck. Specifically, GOTR participants had higher adjusted BMC (g) values compared to controls (2.69 ±0.07 vs. 2.33 ± 0.13, respectively; p=0.018). Baseline analyses of hip structural outcomes showed there were no differences at the intertrochanteric (IT) region of the hip (CSA, CSMI, Z; all p>0.05) and no differences in CSMI and Z at the narrow neck (NN) site (p>0.05). However, there were differences in NN CSA in that GOTR participants had larger adjusted CSA (cm²) values compared to controls (2.01 ± 0.05 vs. 1.76 ± 0.10, respectively, p=0.034) (Table 2).
Table 1 Baseline Descriptive Characteristics [values presented as mean (SD)]

<table>
<thead>
<tr>
<th></th>
<th>Intervention (n=31)</th>
<th>Control (n=9)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>9.77 (1.38)</td>
<td>9.56 (0.73)</td>
<td>NS</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>142.57 (8.59)</td>
<td>140.35 (9.52)</td>
<td>NS</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>37.47 (9.18)</td>
<td>38.64 (13.20)</td>
<td>NS</td>
</tr>
<tr>
<td>Maturation Offset (yrs)</td>
<td>-1.55 (1.05)</td>
<td>-1.78 (0.98)</td>
<td>NS</td>
</tr>
<tr>
<td>MVPA (min/day)</td>
<td>81.94 (20.92)</td>
<td>79.17 (29.20)</td>
<td>NS</td>
</tr>
<tr>
<td>Calcium (mg)</td>
<td>1309.05 (447.61)</td>
<td>1142.13 (557.43)</td>
<td>NS</td>
</tr>
<tr>
<td>Vitamin D (IU)</td>
<td>352.95 (168.35)</td>
<td>332.06 (243.48)</td>
<td>NS</td>
</tr>
<tr>
<td>Whole Body Lean Mass (kg)</td>
<td>26.76 (5.26)</td>
<td>24.43 (3.46)</td>
<td>NS</td>
</tr>
<tr>
<td>Whole Body Fat (%)</td>
<td>30.69 (8.20)</td>
<td>24.80 (8.55)</td>
<td>NS</td>
</tr>
</tbody>
</table>

NS=Not significant p>0.05
Table 2 Baseline Bone Outcomes [mean (SE)]

<table>
<thead>
<tr>
<th></th>
<th>Intervention (n=31)</th>
<th>Control (n=9)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spine BMC (g)</td>
<td>26.28 (0.68)</td>
<td>27.18 (1.279)</td>
<td>NS</td>
</tr>
<tr>
<td>Total Hip BMC (g)</td>
<td>16.85 (0.42)</td>
<td>15.35 (0.80)</td>
<td>NS</td>
</tr>
<tr>
<td>Femoral Neck BMC (g)</td>
<td>2.69 (0.07)</td>
<td>2.33 (0.13)</td>
<td>0.018</td>
</tr>
<tr>
<td>Inter-Trochanter BMC (g)</td>
<td>4.36 (0.18)</td>
<td>4.06 (0.34)</td>
<td>NS</td>
</tr>
<tr>
<td>Narrow Neck (NN)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NN CSA (cm²)</td>
<td>2.01 (0.05)</td>
<td>1.76 (0.10)</td>
<td>0.034</td>
</tr>
<tr>
<td>NN CSMI (cm⁴)</td>
<td>1.20 (0.05)</td>
<td>1.01 (0.102)</td>
<td>NS</td>
</tr>
<tr>
<td>NN Z (cm³)</td>
<td>0.828 (0.03)</td>
<td>0.695 (0.06)</td>
<td>NS</td>
</tr>
<tr>
<td>Intertrochanter (IT)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IT CSA (cm²)</td>
<td>3.20 (0.10)</td>
<td>2.97 (0.19)</td>
<td>NS</td>
</tr>
<tr>
<td>IT CSMI (cm⁴)</td>
<td>5.06 (0.29)</td>
<td>4.74 (0.56)</td>
<td>NS</td>
</tr>
<tr>
<td>IT Z (cm³)</td>
<td>2.13 (0.09)</td>
<td>2.06 (0.18)</td>
<td>NS</td>
</tr>
</tbody>
</table>

NS=Not Significant p>0.05
CSA = Cross Sectional Area; CSMI = Cross-Sectional Moment of Inertia; Z = Section Modulus

Process Evaluation Results

The GOTR program was delivered on two days of every week over a 10 week period. Curriculum based activities were performed on all 20 of the delivery days for GOTR participants enrolled Fall 2008-Summer 2009 and all 19 delivery days for GOTR participants enrolled Spring 2009-Winter 2010. Each session was approximately 75 minutes in length including an activity which introduced the lesson, warm-up and stretching before the running work-out, and the work-out itself (see appended sample lesson plan). All, but one participant attended at least 75% of the sessions. The participant not meeting the 75% attendance requirement only attended 65% (13/20) of the lessons. Excluding her from the analyses however, did not significantly change the outcomes. Overall attendance for the group ranged from 65%-100% attendance. Although each session was conducted regardless of the weather,
suboptimal weather (rain, cold temperatures) was noted as a factor which affected the participants’ physical activity levels. During practices in which it was raining or cold, although not directly measured, qualitative reports from the coaches indicate that some participants did not engage in as much activity. Depending on the GOTR site, some groups were able to have access to an indoor facility when the weather was not optimal. Although this allowed for the lesson to be conducted without the weather interfering, there were times that modifications to the lesson had to be made. Similarly, as the lessons are designed for groups of 7-12 girls (Barker, 2005), practice sessions with low overall attendance required the lesson’s activities to be altered. Every participant was encouraged to fully participate in each activity, however it was not mandatory. As such there were occasions when participants elected not to participate at all or to only participate at a minimal level (i.e. walking instead of running). Although the program is a running-based program, it is designed to encourage physical activity in its participants. Thus, walking, although not as vigorous as running, is acceptable for the purpose of the program’s intentions.

**Bone Outcomes at Follow-Up**

Group comparisons in bone outcomes at follow-up are presented in Table 3. After adjusting for initial BMC, age, height, weight, maturation (years from PHV), mean MVPA, calcium and vitamin D, we found no differences between groups at the spine and total hip sites (p>0.05; Table 3). The differences in BMC (g) at the femoral neck region of the hip remained despite adjustment for initial values with GOTR participants exhibiting higher adjusted values (2.94 ± 0.03 vs. 2.8 ± 0.06, respectively, p=0.048). Unlike baseline, there were also differences at the intertrochanter, with GOTR participants exhibiting higher adjusted BMC (g) values compared to controls (5.1± 0.09 vs.4.67 ± 0.17, respectively, p=0.039). There were no differences between groups on any of the bone structural outcomes (p>0.05), though there was a trend at the NN CSA site with GOTR exhibiting higher adjusted NN CSA values (p=0.055). Removing calcium and vitamin D (which showed no influence on any bone outcomes) had the effect of increasing the observed power to detect a group effect (p=0.046). Removing calcium and vitamin D from the models did not change the outcomes of any other follow-up analyses.
<table>
<thead>
<tr>
<th>Table 3 BMC and Bone Structural Outcomes at Follow-up [mean (SE)]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intervention</strong> (n=31)</td>
</tr>
<tr>
<td>Spine BMC (g)</td>
</tr>
<tr>
<td>Total Hip BMC (g)</td>
</tr>
<tr>
<td>Femoral Neck BMC (g)</td>
</tr>
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</tr>
<tr>
<td>Narrow Neck (NN) (\text{NS})</td>
</tr>
<tr>
<td>NN CSA (cm(^2))</td>
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<tr>
<td>NN CSMI (cm(^4))</td>
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<tr>
<td>NN Z (cm(^3))</td>
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<tr>
<td>Intertrochanter (IT)</td>
</tr>
<tr>
<td>IT CSA (cm(^2))</td>
</tr>
<tr>
<td>IT CSMI (cm(^4))</td>
</tr>
<tr>
<td>IT Z (cm(^3))</td>
</tr>
</tbody>
</table>

NS=Not Significant \(p>0.05\)

CSA= Cross Sectional Area; CSMI= Cross-Sectional Moment of Inertia; Z= Section Modulus

**Influence of Covariates on Bone Outcomes**

In all BMC and bone structural analyses at follow-up, there was a significant influence of initial bone values (\(p<0.001\) at all sites). While maturation had a significant influence in the BMC models at baseline, accounting for a significant proportion of the variability in BMC and bone structure at all sites (\(p<0.001\)), this effect was diminished by the inclusion of initial values at follow-up. There was no effect of calcium and vitamin D at any BMC or bone structure site at baseline or follow-up. Likewise, the inclusion of mean MVPA at follow-up had no significant influence in any of the models examining BMC or bone structure. Analyses were repeated using an adjusted MVPA value which included “non-monitored” activities such as swimming or athletic events in which wearing the activity monitor posed a safety concern, with no significant change in any of the models. Thus the
adjusted BMC and bone structure means presented in Table 3 and Figure 1 include the unadjusted MVPA values.

**BMC Changes between Baseline and 9-Months**

Figure 1 presents the percent change in BMC values from baseline to the 9-month follow-up adjusted for initial values, age, height, weight, maturation (yrs from PHV), calcium, vitamin D and MVPA. The *GOTR* group gained 6% more bone at the femoral neck and 10.5% more bone mass at the trochanteric region over the 9-month period compared to controls. This difference exceeds the precision error calculated for femoral BMC (1.8%) and for the intertrochanteric region (4.9%) within this sample of children and can be considered a meaningful difference.

**Figure 1** Data are presented as the percent change in BMC from baseline to follow-up. The intervention group exhibited greater changes at the femoral neck and the trochanteric regions of the hip (p<0.05). The *GOTR* group increased 6% and 10.5% over controls at the femoral neck and the trochanter, respectively. Values presented are adjusted for initial bone values, growth, maturation, calcium, vitamin D, and MVPA.
Meeting Physical Activity Recommendations

To determine whether participation in GOTP was important in helping young girls meet the physical activity minimum recommendations (60 minutes/day of MVPA), we ran a one-sample t-test at each measurement occasion to determine whether the mean MVPA was different from a criterion score of 60 minutes. Six participants were missing data for at least one time point and were excluded from analyses. Reasons for lost data included technical failure or non compliance. In addition, eight participants had fewer than three monitored days on one of the four measurement occasions. Analyses were performed with these participants included and repeated with them removed. There were no differences in the outcomes of these analyses. As such, reported data include all participants with monitored data at each time point (n=25). Table 4 presents the one-sample t-test results. At baseline, girls were engaged in the GOTP program during the time when physical activity data were collected. Thus the MVPA score at this time point captured GOTP participation. At baseline, GOTP participants recorded a mean value of 81.1 ± 21.3 minutes of MVPA per day. This reflects a mean difference of 21.1 minutes above the criterion value of 60 minutes with a 95% confidence interval of 12.46-29.68, p<0.001. There were no differences between the criterion value of 60 minutes and mean MVPA at 3 months (p>0.05). At 6 months, GOTP participants were slightly above the criterion of 60 minutes (p=0.05) and significantly below the criterion value of 60 minutes at 9-months (p=0.017). However after adjusting for multiple comparisons the differences observed at 6- and 9-months were no longer significant (p>0.0125). When analyses were repeated including all available data for each time point (baseline, n=39; 3 months, n=40; 6 months, n=37; 9 months, n=37), there was still a significant difference at baseline with a recorded mean MVPA value of 81.3 ± 22.4 minutes (mean difference = 21.3 with a 95% confidence interval of 14.1-28.7; p<0.001). The mean MVPA did not differ significantly from 60 minutes at 3-, 6-, or 9-months (p>0.0125). When repeating the analyses with the adjusted MVPA data (which included non-monitored time from activities such as swimming) the results did not change (p>0.0125). Thus data reported in Table 4 include the mean unadjusted MVPA on the participants who had complete data at every time point (n=25).
Table 4 One Sample t-test: Minutes of MVPA among GOTR Compared to a Criterion Value of 60 Minutes

<table>
<thead>
<tr>
<th>MVPA</th>
<th>Mean MVPA (SD)</th>
<th>Mean Difference</th>
<th>Lower</th>
<th>Upper</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline (min/day)</td>
<td>81.1 (21.3)</td>
<td>21.069</td>
<td>12.46</td>
<td>29.68</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>3-Month (min/day)</td>
<td>65.1 (25.1)</td>
<td>5.098</td>
<td>-5.04</td>
<td>15.24</td>
<td>NS</td>
</tr>
<tr>
<td>6-Month (min/day)</td>
<td>67.1 (17.6)</td>
<td>7.104</td>
<td>.00</td>
<td>14.21</td>
<td>NS</td>
</tr>
<tr>
<td>9-Month (min/day)</td>
<td>50.0 (19.9)</td>
<td>-9.99681</td>
<td>-18.0200</td>
<td>-1.9736</td>
<td>NS</td>
</tr>
</tbody>
</table>

NS = Not significant (p>0.0125)

Differences in MVPA Patterns within and between Groups

Repeated measures analysis of variance allowed us to examine the effect of time within and between the intervention and control groups and to examine group differences in MVPA. The effect of time was significant (p<0.001) with participants in both groups recording significantly more MVPA at the first visit compared to any other time point after adjusting for multiple comparisons (p-value ranging from p<0.001 to p=0.015 in pairwise comparisons). Figure 2 presents the mean MVPA for both groups over the study period. Both groups also recorded MVPA values at the 9-month visit that were significantly lower than baseline and 3 month visits (p<0.001 and p=0.01). The test of between subjects effects revealed no significant differences between groups in mean MVPA (p=0.294). This was consistent across all time points. No differences were observed when adjusted MVPA was included in place of the unadjusted MVPA in the repeated measures analysis.
Figure 2 Data are presented as the mean MVPA at each time point for GOTR participants (solid line) and controls (dashed line). There were no differences between groups at any time point $p>0.05$. Differences over time were significant for both groups: (* = $p<0.05$ compared to baseline for GOTR group; ‡ = $p<0.05$ compared to baseline for Control group).

Practically speaking, the most important consideration is whether or not the girls were meeting the minimum recommendation (60 minutes of MVPA daily). Frequency data show that over 80% of GOTR participants were getting at least 60 minutes of MVPA daily during the collection period (baseline) when they were participating in the GOTR program. The proportion of girls in the GOTR group getting sufficient MVPA was lower at each subsequent measurement occasion (55%, 69% and 43% at 3-, 6-, and 9-months, respectively).
CHAPTER 5

DISCUSSION

The purpose of this study was to examine the effects of participation in Girls on the Run (GOTR), a community based running program, on both physical activity and bone related outcomes in girls aged 8-12. Our first aim was to examine whether participants in GOTR were meeting the minimum recommended dose of physical activity for youth [60 minutes per day of moderate to vigorous physical activity (MVPA)]. We hypothesized that GOTR participants would meet this recommended dose, as measured by accelerometry, at each measurement occasion. There were no observed differences in MVPA between our intervention and control groups at baseline. On average, participants in both groups exceeded the recommendation of 60 minutes of MVPA per day at baseline. However this difference was only statistically significant among the GOTR participants. During this initial assessment all participants in the intervention group were participating in the GOTR program and 80% were obtaining at least 60 minutes of MVPA daily. Contrary to what we hypothesized however, there was not a persistent effect of increased MVPA across the study duration. In fact the amount of MVPA accrued over the 9 month study decreased in the intervention group. At 3 months there was no significant difference between the MVPA accrued and the 60 minute per day recommendation; at 6-months GOTR participants were only achieving slightly above 60 minutes of MVPA per day; and at 9-months MVPA levels were significantly below the recommended level. Although the control group demonstrated a similar pattern in MVPA, with highest levels at baseline and lowest levels at the 9-month follow-up, the differences at each time point compared to baseline were not as large as with the intervention group.

For our second aim we examined bone outcomes in GOTR participants compared to a control group. Specifically we hypothesized that GOTR participants would demonstrate enhanced bone mineral content (BMC) of the hip, spine and whole body, and improved bone strength and structure of the femoral neck [cross-sectional moment of inertia (CSMI), cross sectional area (CSA) and section modulus (Z)], above baseline and compared to a control group as measured by dual-energy x-ray absorptiometry (DXA) at 9-months. At baseline there were no observed differences in total BMC of the intertrochanter, hip, or spine between groups. However, participants in the intervention group demonstrated significantly greater
BMC at the femoral neck and greater NN CSA values compared to the control group. At the 9-month follow-up the differences in femoral neck BMC between groups remained, even after adjusting for the initial difference in the GOTR group. A 6% greater increase in femoral neck BMC compared to the controls was observed. The GOTR participants also demonstrated significantly greater BMC at the intertrochanter at the 9-month follow-up compared to controls. We observed a 10.5% greater accrual in BMC at the trochanteric region over the 9-month study duration compared to the control group. No differences at follow-up were found between the intervention and control groups for hip and spine BMC or bone structural outcomes. Though we found no differences in BMC at the spine and no differences in structural outcomes, our hypotheses were supported in part. The increased BMC observed at the femoral neck and intertrochanter are encouraging and merit further investigation of GOTR’s potential to benefit skeletal development among young girls.

**Significance of Results**

This study is novel in that it examined the influence of a popular, nationally known, after-school program targeting young girls, on bone mass and structure outcomes. To date, this is the first study examining these outcomes relative to the Girls on the Run program. Further this study objectively monitored physical activity during and following participation in this program in order to determine whether participation contributes meaningfully to girls accruing the recommended levels of MVPA. GOTR differs from other after-school physical activity programs in that it is comprised primarily of running activities. Specifically, participants support one another in their individual efforts to complete a 5 kilometer race through running-centered activities and lessons designed to increase self-esteem and self-awareness in young girls. The significance of this study is further highlighted given the dearth of information regarding the influence of running on the young skeleton. Although many studies have examined the effects of physical activity on the growing skeleton (Bailey et al., 1999; Gunter et al., 2008; Janz et al., 2004; Janz et al., 2007; MacKelvie et al., 2003; MacKelvie et al., 2004; McKay et al., 2005; Rizzoli et al., 2010), to our knowledge, there have been no reports on the specific effects of running in a young female population.

Researchers examining the influence of running on the mature skeleton have reported mixed results (Guadalupe-Grau et al., 2009; Snow-Harter et al., 1992). The lack of a response to running in the mature skeleton is generally attributed to the fact that running, or other
endurance training interventions, do not have the same bone loading forces observed to enhance bone mass as the forces associated with other weight bearing activities such as resistance training (Guadalupe-Grau et al., 2009). In addition, the low/moderate impact forces associated with running in individuals who run regularly may not be that much greater than the forces experienced during habitual loading such as standing and walking (Snow-Harter et al., 1992). However, the young skeleton is more responsive to mechanical loading. Thus, if there are in fact benefits to the growing skeleton from running not observed in the mature skeleton, as our results suggest, this information can be used to promote running as broadly beneficial among children. The results of our study suggest that running, which has shown minimal positive effects on the mature skeleton, deserves further examination regarding its osteogenic potential for the growing skeleton. Given that running is an activity requiring minimal experience or equipment for participation, it is feasible to incorporate this activity into more community-based physical activity programs. Finally, as running is an aerobic activity, promoting it among young children may also serve to combat the growing obesity crisis in addition to supporting musculoskeletal health.

One of our major findings was that GOTR participants were getting significantly more than 60 minutes of MVPA daily during the baseline data collection period when they were participating in the GOTR program. This finding is of interest when we consider the observed drop in physical activity levels during the subsequent measurement occasions when girls were not participating in GOTR; contrary to our hypothesis. We had expected that participation in GOTR might provoke a sustained interest in running and physical activity generally, however that does not appear to be the case. While the mean MVPA was slightly more than 60 minutes per day at the 3 and 6-month visits, these were not statistically significant differences. There was however a statistically lower level of MVPA at these time points compared to baseline when they were participating in GOTR. At the 9-month follow-up, girls had been out of the program for 6 months and the mean MVPA was significantly lower than the recommended minimum of 60 minutes per day and significantly lower than baseline. This is important in that it highlights the significant contribution after school physical activity programs can have on young girls’ physical activity levels.

There are other potential influences that could account for the observed drop in physical activity among study participants. We recognize that seasonal changes can influence physical activity levels, particularly during inclement winter months, however, our design
controlled for this to some extent. We recruited two cohorts of participants. The first began in fall 2008 with non-participation in *GOTR* during winter, spring and summer 2009. The second cohort began in spring 2009 with non-participation in *GOTR* during fall 2009, winter and spring 2010. Within cohort examination showed that in both cohorts, the highest levels of MVPA occurred during their respective baselines’ when they were participating in *GOTR* and the lowest levels were at the 9-month time point; summer for cohort 1 and fall for cohort 2. Thus, we feel confident that the increased MVPA at baseline compared to subsequent visits is likely attributable to *GOTR* and not reflective of a seasonal effect and that participation in the *GOTR* program increased MVPA in its participants while they were enrolled in the program compared to measured time points when they were not participating in *GOTR*.

Other afterschool interventions such as the Trial of Activity in Adolescent Girls (TAAG) and the Coordinated Approach to Child Health (CATCH) afterschool program, CATCH Kids Club (CKC), have resulted in similar increases in MVPA among participants (Kelder et al., 2005; Lytle, 2009). CKC is a curriculum based program designed to decrease the risk of cardiovascular disease in 3rd to 5th grade students using nutrition education and physical activity lessons (Kelder et al., 2005) while TAAG uses the socio-ecological model to decrease the decline in physical activity levels among young girls through the development of supportive environments (Lytle, 2009). Both of these programs however, were offered five days a week as opposed to the two day per week *GOTR* sessions. TAAG also targeted middle school aged girls, slightly older than the 8-12 year old *GOTR* target population and CKC was designed for both boys and girls (Kelder et al., 2005). With the time after school recognized as one of the largest blocks of discretionary time during a child’s day, it is logical to consider this as an opportune time to implement interventions which promote physical activity to potentially to increase total daily MVPA among children participants (Koplan et al., 2004).

Also a major finding was that *GOTR* participants had greater femoral neck and trochanteric BMC at follow-up compared to the control group which may translate to enhanced bone outcomes in a growing population if these effects persist. While many others have found enhanced bone mass among young girls in response to targeted physical activity, this is the first to show such an effect in response to a running program in this population. At the very least the results of this study support the need for more research examining the effects of participation in *GOTR*, as well as other community based running programs, on young girls’ physical activity levels and skeletal health.
Comparison with Previous studies

MVPA

Research has demonstrated that participation in structured community based physical activity programs has the potential to make a difference in observed levels of MVPA (van Slujis et al., 2007). Through direct observation CKC demonstrated substantial increased MVPA during the afterschool program in its intervention group (Kelder et al., 2005). Although this afterschool intervention targeted both boys and girls, the age group, with a mean age of nine, was similar to ours supporting the effectiveness of such programs in the target population. Programs such as CKC and GOTR, which are directed toward younger children, may be of particular benefit to young girls. Evidence suggests that physical activity levels tend to drop rapidly among girls as they enter adolescence (Riddoch et al., 2007; Spinks, Macpherson, Bain, & McClure, 2006; Trost et al., 2008) and the success of programs targeting adolescent girls are limited (van Slujis et al., 2007). As such, exposure to effective programs prior to adolescence may buffer this decline. However, as we observed, the higher levels of MVPA observed while girls were participating in GOTR did not persist. Thus, there needs to be opportunities for sustained participation in programs. With respect to the local GOTR program that provided the intervention for this study, girls do not have the opportunity to participate all year as the program is not offered during all seasons. Further, the program is cost prohibitive for many and as such may be inaccessible to segments of the population.

In the TAAG study, (Lytle, 2009), one of the significant factors identified as having a positive influence on activity levels was social support from friends (Lytle, 2009). Participants in GOTR are younger than those who participated in TAAG, however, as a program targeted to girls specifically, the social support and group dynamics may contribute to increased program participation and involvement. Both the CKC and TAAG after school programs these were offered every day, whereas GOTR was only offered twice per week. Our results showing that participants in GOTR accumulated more MVPA while participating in the program, suggests participation in gender specific structured physical activity for as little as two days a week may help 8-12 year old girls meet the MVPA guidelines.

More research in younger populations is necessary to gain a better understanding of the effectiveness of physical activity interventions outside of the school setting (van Slujis et al., 2007). Much like TAAG, which was intended to link schools with a community based
physical activity program, \textit{GOTR} partners with local schools which provide the site, thereby making it easier for girls to participate in the on-site after school program. Further, \textit{GOTR} also provides an established physical activity curriculum and program support to individual program coordinators and engages volunteers to deliver the program. This strategy appears to be a feasible way to increase physical activity in pre-adolescent girls.

\textit{Bone Outcomes}

Research supports that optimizing bone outcomes by promoting weight-bearing physical activity during the purported “window of opportunity” when the skeleton is experiencing accelerated growth can result in lasting bone outcomes (Baxter-Jones et al., 2008; Baxter-Jones, et al., 2003; Forwood et al., 2006; Gunter, et al., 2008; Gunter et al., 2007; Gunter, Baxter-Jones & Mirwald, 2007; Nurmi-Lawton et al., 2004; Warden et al., 2007). The precise dose of activity which optimizes bone growth outcomes acutely in this population is still being researched. Although it is known that these changes in bone can persist, exactly how long they remain is unknown.

It is well documented in the literature that higher levels of MVPA, specifically activities which are weight-bearing in nature, result in greater BMC values in growing populations (Fuchs et al., 2001; Janz, et al., 2004; Janz et al., 2007; Gunter, Baxter-Jones & Mirwald, 2007; Macdonald et al., 2008; MacKelvie et al., 2003; MacKelvie et al., 2004; McKay et al., 2005; Petit et al., 2002; Rizzoli et al., 2010). The mechanostat theory states that greater amounts of physical activity should be associated with more optimal bone outcomes independent of influences related to normal growth (Bailey et al., 1999). Specifically, bone responds to higher loading through favorable changes in mass, size, and architecture (Schoenau & Frost, 2002). In support of this, several researchers have reported that school-based physical activity programs targeting bone in young children have found positive changes in response to these programs (Gunter et al., 2008; Gunter, et al., 2007; Macdonald et al., 2008; McKay et al., 2005; Petit et al., 2002). Most of the interventions associated with these studies were delivered over a 9-month period to align with the school year. Our study length was also 9-months, but the intervention was only approximately 3 months and yet we found similar positive benefits at the femoral neck compared to studies of longer duration.

Another difference between our study and other studies examining the effect of school-based interventions on skeletal development in young children is the exercise modality.
Most of the school-based studies reviewed employed jumping as the primary component of the interventions. For example, Fuchs et al. (2001) found gains at the hip nearing 5% over 9-months among children who participated 2-3 times per week in a jumping protocol and Gunter et al. (2008) found a nearly 8% increase at the femoral neck, trochanter and total hip in response to a similar intervention. In another 9-month intervention, researchers looked at the effects of jumping off a box in all four directions three times a week in a population sample of female twins with a mean age of 8.7 years (van Langendonck, Claessens, Vlietinck, Derom, & Beunen, 2003). Despite a relatively small sample size (n=21), osteogenic affects were observed at the femoral neck and proximal femur in those who participated in the intervention and did not have history of participating in high impact sports (van Langendonck, et al., 2003). In their 7-month intervention which integrated 10 minutes of jumping into physical education classes three time per week, Petit et al. (2002) found increases in BMC as well as bone structure and strength changes among girls in the early stages of puberty. And “Bounce at the Bell,” an eight month intervention which incorporated 10 minutes of jumping into classroom activities three times per week, provoked increases of approximately 2% in BMC as well as beneficial changes to bone structural outcomes at the proximal femur and intertrochanteric regions in their intervention group (McKay, et al., 2005).

While jumping predominates as an intervention modality to enhance bone growth among younger children, there have been studies which relied upon a different physical activity stimulus. For example, Heinonen et al. (2000) used intervened in a population of school-age girls with a step-aerobics program that was delivered two days per week for 9-months. Pre-menarcheal girls demonstrated increased BMC at the lumbar spine and femoral neck while girls who were post-menarcheal did not show any statistically significant increases in the bone parameters measured (Heinonen et al., 2000). This is likely due to two factors – the first relates to the diminishing responsiveness of the skeleton to applied loads with maturation, and the second is the potentially lower stimulus from step aerobics compared to jumping. As more evidence to the former, Weeks and Beck (2010) conducted a recent study examining the relationships between bone mass, physical activity and maturation status in adolescent girls and boys. Similar to our study, they used years from peak height velocity as their marker of maturity. After controlling for years from PHV, they found no influence of physical activity on bone parameters among adolescent girls. Among boys however, physical activity had a positive effect on bone independent of maturation. The authors hypothesized
that factors determining overall physical growth and maturity may exert a particularly strong influence on the postmenarcheal female skeleton (Weeks & Beck, 2010). In our study we controlled for years from PHV in our analysis and still observed that participation in \textit{GOTR} was associated with increases in bone mass at the femoral neck. However, most girls in our cohort were pre-menarcheal compared to the largely post-menarcheal cohort that made up the participant group in the study reported by Weeks and Beck (2010). Although post-menarcheal girls may still benefit from such bone loading activities, the research supports that the opportunity to enhance skeletal growth through bone loading activities in girls is greater during the time before the onset of menses.

We did not observe differences between groups across all measured bone variables. However, we did observe a positive influence of participation in \textit{GOTR} at the femoral neck and trochanteric region of the hip. While we hypothesized this to be the case, we also expected that \textit{GOTR} would result in sustained increases in MVPA over the 9-month period and that MVPA would be related to any observed bone changes. This however was not the case. While MVPA was higher during the times the girls were involved in \textit{GOTR}, the high level observed during this initial measurement period was not maintained and the changes we observed in bone were not attributed to MVPA levels in statistical models. Only initial bone values and participation in \textit{GOTR} had a significant effect on bone values at follow-up. However, it is possible that our objective measure of MVPA was not capturing the true bone loading nature of the running-based activities. Although there was no difference in the MVPA levels of \textit{GOTR} participants compared to controls, there may be a difference in the bone loading nature of the activities group members participated in which influenced bone related outcomes.

Accelerometers are used in many research studies and are accepted as a valid and reliable tool to objectively measure physical activity (Ward, Saunders, & Pate, 2007). However, our data suggest that accelerometers may not be the best tool when trying to relate physical activity behavior to changes in bone. Even though accelerometers are able to collect data relative to physical activity intensity, perhaps a limitation to the use of accelerometry is the inability to accurately characterize activities which are bone loading in nature.

There is always the potential for an alternative explanation relative to the observed changes in femoral neck BMC among \textit{GOTR} participants. However, we examined the potential of numerous covariates to explain changes in bone independent of \textit{GOTR}
participation. These included initial BMC values, dietary factors such as calcium and vitamin D, maturation, body composition and MVPA across the 9-month study period. Aside from initial bone values, only group membership explained a significant proportion of the variability in follow-up femoral neck and trochanteric BMC values.

Though we did not directly query participants as to their participation in organized sports, it is possible that greater levels of organized sport participation are responsible for the greater BMC changes observed among GOTR participants. Early studies examining the effects of physical activity on bone have demonstrated consistent participation in athletics such as tennis, squash, and gymnastics, to be associated with greater bone mineral accrual in growing populations (Bass et al., 2002; Bradney, et al., 1998; Huddleston, Rockwell, Kulund, & Harrison, 1980; Kannus et al., 1995; Llodd et al., 2000). And Guadalupe-Grau et al. (2009) reported that the effects of sport participation on bone are greater in individuals who began sport participation around the time of the pubertal growth period (Guadalupe-Grau et al., 2009). While none of our controls were involved in organized sports (by the nature of the study design), anecdotal information suggest that several of the GOTR participants were engaged in some form of sport during the measurement occasions that they were not enrolled in GOTR. It is hypothesized that positive bone outcomes associated with sport participation may be due to the nature of sport, which may encourage participants to participate in higher intensity physical activity. However, increased levels of physical activity as a result of sport participation among GOTR participants were not reflected in the objectively measured MVPA data. Another hypothesized mechanism for the effects of sport participation on bone relates to the consistency of practice and game sessions which result in regular exposure to potential bone building activity. Thus another potential explanation for the bone benefits observed among GOTR participants could relate to consistent, regular exposure to bone building activity during the intervention period. Though we did not directly assess the impact forces experienced during GOTR practice sessions, we know GOTR participants recorded their highest MVPA levels during the time they were engaged in this program. Further by design, participants experienced a consistent dose of physical activity as the program is offered two days per week. One additional benefit of GOTR that is different from most organized sports is that GOTR does not have a competition component. This may make it more appealing to girls less likely to participate in athletics. Our data suggest that girls, who may shy away from
competition, may be able to experience some of the skeletal benefits of organized sport without the competition through participation in GOTR.

We found no influence of participation in GOTR on bone structural outcomes. However, several factors may have contributed to our inability to observe a detectable difference at this site. First, this is a relatively new technology and the error variance is considerably higher than it is with BMC measures. Thus the higher level of error (NN CSA CV: 3.0%, NN CSMI CV: 7.7%) combined with relatively small changes expected over a 9-month period and the small sample size, likely minimized our ability to observe differences between groups as it related to bone structural outcomes. It is also possible that changes in bone structure require a longer intervention period. One example is the Action Schools BC! program. Action Schools BC! is a school-based intervention in which teachers incorporated about 15 minutes of bone-loading activities into the school day. In a cluster randomized trial, girls who participated in this 11-month intervention demonstrated greater increases in bone structure outcomes (femoral neck section modulus) than controls (MacDonald, 2008). Although the intervention duration was longer and more frequent than ours the actual time spent doing the activities (15 minutes) was relatively short compared to other interventions. Still others have observed positive changes to bone structure relative to increased daily physical activity levels (Janz, 2004; Forwood, 2006).

**Limitations**

Despite our positive findings regarding greater bone mineral accrual in the GOTR participants as well as higher MVPA levels while participating in GOTR, there are a number of limitations to our study which should be discussed. First of all, this study specifically examined the GOTR Willamette Valley program, thus our results cannot be generalized to other GOTR programs. Our small total sample size and especially our small control group sample size diminished the overall power to detect differences between groups, subsequently limiting the practical significance of our study as well. Every effort was made through a variety of recruitment techniques to enroll as many participants from GOTR Willamette Valley as possible. Fliers were distributed, information sessions were held, and an attempt was made to contact every parent of each GOTR participant enrolled during the time period of our study. Parents unwilling to allow their daughters to take part in the study most often stated busy schedules and lack of time as barriers to participation. Given the nature of our data collection,
which required eight visits to the Oregon State University Bone Research Laboratory, some parents were understandably not willing to commit to this. Specifically one parent stated, “the demanding nature of the project,” was the reason they chose not to allow their daughter to participate. Other parents expressed concern about the radiation exposure from the DXA technology despite explanation given by the researcher that these risks were minimal.

Even with rolling recruitment for control participants it was much more difficult to recruit participants not involved in any organized physical activity than originally anticipated. Although a variety of attempts were made by recruiting through OSU, press releases, the Corvallis School District, local churches, and the Boys and Girls Club few eligible participants responded. This may have had to do with the demands of the study, degree of interest among the target population, or inadequate incentives provided.

As a part of KidSpirit, an organization for youth programming through OSU all volunteer training and coordination for the GOTR program was conducted by the KidSpirit program director. Volunteer coaches were primarily college aged individuals. This was advantageous in that the participants often looked up to them in ways different than other adults and as coaches they provided positive leadership and mentorship to the participants. However, having college students as volunteers for a community program also has its challenges. Although not the case for all coaches, some tended to have competing priorities which prevented them from participating in all of the training and practice sessions. Inconsistencies in coaching staff and coach availability may have decreased the effectiveness of the delivery of the program curriculum. Additionally, after the coaches training there was insufficient compliance with process evaluation components at each site to ensure that the program was being carried out as directed.

Environmental factors and participation among girls sometimes created challenges beyond the control of the researcher or GOTR coach. As a program based outdoors, suboptimal weather (rain, cold temperatures) sometimes made it difficult to conduct each lesson as the curriculum directed. Program delivery was also affected when the number of girls who showed up on a particular day was fewer than the number of participants required to carry out a specific activity, thus requiring slight modification of the curriculum. Although GOTR is primarily a running based program, it does not require all participants to run. The goals of the program “are to encourage positive emotional, mental, social, spiritual, and physical development” (Girls on the Run International, 2008). Physical activity participation
and running was highly encouraged, but could not be forced upon the participants. As such, several GOTR participants often chose to walk during practice rather than run. Each lesson also included a variety of discussion topics. Depending on the topic for each lesson, some topics generated more discussion than others. During practices when discussions went longer than planned, the amount of time spent doing physical activity was consequently decreased. However, even with these program limitations we still observed greater levels of MVPA during the measurement period when participants were enrolled in the program. This suggests that although running may be beneficial for the attainment of the recommended levels of MVPA perhaps it is not required. It may be that a combination of running and walking is adequate for fulfilling the MVPA requirements among young girls.

Finally, as it relates to our MVPA outcomes – we cannot be certain that the higher levels of MVPA observed during the time period when the program was in session are entirely due to the program. Had we been able to identify GOTR participants prior to their enrollment in the GOTR program – we could have collected pre-intervention MVPA data. If we had observed higher MVPA levels during the program than pre and post-intervention, we would feel more confident asserting that the program was responsible for the higher MVPA levels observed at this time point.

Although the positive changes in bone outcomes we observed in the GOTR group are encouraging, we were surprised that the changes in bone did not appear to be influenced by MVPA levels. However, as noted previously, we speculate that accelerometry may not be the best method for assessing the bone loading nature of activities, and suggest future research explore this area. While the capacity of accelerometers is expanding, they are somewhat limited in their ability to detect specific types and intensities of movements such as swimming and cycling. It is possible that the greater bone loading nature of some activities (for example several short sprints or jumps versus continuous brisk walking) may not be reflected in the MVPA values as measured by accelerometers. In the above example, the higher ground reaction forces associated with sprints could have a more powerful influence on bone compared to a lower impact bout of vigorous walking, even if the walking occurs over a significantly longer period of time. An example of this from running activities included in the GOTR program are relay races requiring participants to sprint or walk quickly over a short distance and then stop or slow down for a period of time. The MVPA values recorded may
not differ compared to walking at a moderate pace for the same period of time, but the bone
loading nature of the sprinting is likely greater compared to walking.

All participants were instructed to record the any activity they did while not wearing
the accelerometer in their “Wear-Time Log.” However the limitations associated with this
assessment are recognized. For example, some participants mentioned that they sometimes
forgot to put the accelerometer back on after taking it off for an activity such as swimming.
Some participants indicated in the wear time log that they were “swimming” for the entire
time the accelerometer was noted for being off, while others would attempt to recall specific
activities done while the accelerometer was not being worn. As both control and intervention
participants spent a fair amount of time swimming during the summer activity monitoring
periods, it was important that we control for these limitations. We did so by creating criterion
for wear time. For example, if someone did not accrue at least 600 minutes over the course of
a monitored day – that would reflect insufficient wear time. Thus, it is likely that someone
who went swimming early in the day and neglected to put the device back on, would not
achieve their 600 minutes and that day would subsequently be removed from analysis. In
addition, an adjusted MVPA variable was created to account for reported, but non-monitored
time. Adjusted MVPA was determined by integrating one third of the amount of time
recorded, up to 60 minutes, of the activities which occurred during the non-wear time, to the
objectively measured MVPA. Analyses of MVPA over time and relative to bone outcomes
were performed using both adjusted and unadjusted MVPA values and both were reported in
the results.

Another limitation in our study design was that we did not ask about and account for
participation in organized sports during the 9-month enrollment period. An analysis of sport
participation was performed retrospectively based on researcher recall. No effect of sport
participation was found, but the subjectivity of this assessment should be recognized. We also
did not directly assess whether participants enrolled in a subsequent session of GOTR. Based
on researcher recall it is known that one participant did participate in one additional session
following the initial 3-month intervention, but this is unknown for the remaining participants.
However, it is our assumption that any increased activity associated with continued
participation would have been captured in our assessment of MVPA. However, had we asked
about subsequent participation in the program, this information would have given greater
insight to the observed varied levels of MVPA across time points.
Strengths

Despite these limitations this study had several strengths. With more than 150 councils in the United States and Canada, GOTR is a well-established physical activity program with a set curriculum. The program we chose to examine for our study is run through Kid-Spirit, a well-recognized local community organization. This made our role in the logistics of the program execution minimal. The strengths of the outcomes we measured include a thorough assessment of not only BMC, but also bone structural outcomes and an objective measurement of physical activity over four different time points throughout the year. Although more studies in growing children are now assessing bone structure in addition to bone mass, this study further contributes to the growing body of knowledge in this area. Obtaining DXA and HSA precision data in our sample population supports the reliability of our results while at the same time contributing to the precision data which already exists which is important for current and future research.

Many studies examining physical activity outcomes use an objective assessment, few studies however, implement follow-up beyond post intervention in order to determine whether there is a persistent positive effect or a detraining effect (van Sluijs et al., 2007). Further, to the best of our knowledge no studies to date have obtained four consecutive accelerometry measurements within a 9-month period and related these measures to bone outcomes. Not only did our study perform immediate follow-up assessments post intervention (at 3-months post baseline assessment), but multiple follow-up assessments were carried out at six and nine months after the intervention had ceased. This provides valuable information about physical activity variation throughout the study period as well as information about physical activity variation over different seasons for both the intervention and control group. Additionally, it helps us to understand the potential persistent influences of the GOTR program on young girls’ objectively measured MVPA levels.

An additional strength of this study relates to the specific exercise stimulus. There are many studies which demonstrate that jumping is an effective stimulus (Fuchs & Snow, 2002; Gunter et al., 2008; McKay et al., 2005; Petit et al., 2002), but other studies have examined either general physical activity (Bailey et al., 1999; Janz et al., 2007; McKay, Liu, Egeli, Boyd, & Burrows, 2010) or interventions that which included a variety of physical activity modalities including running, skipping, jumping, and dancing to influence bone growth (Daly & Petit, 2007). GOTR uses primarily running and walking. This is significant for two reasons.
First, while having many different modalities of physical activity within a single program can be advantageous for promoting variety and perhaps maintaining interest among participants, it is not possible to determine which specific activity may be influencing changes in bone over the intervention period. With the exception of jumping, we cannot really point to other specific, individual activities shown to influence bone positively in young children (Gunter et al., 2008; McKay & Smith, 2008). This is one reason why establishing an exercise prescription for bone health remains a difficult task. Our study suggests that another specific type of activity – running- may also be beneficial for skeletal development in growing girls. However there still exists a great need to evaluate this further and to identify additional specific, effective bone building activities and the effective dose associated with positive responses. We sought to examine the influence of running as few studies exist in the current literature which utilize running as the primary physical activity component– particularly in young children. Thus our study results are a valuable contribution to this area of research.

Finally, another strength was the high adherence to the GOTR program among our intervention group. Many studies have identified intervention exposure and adherence as challenges to the effectiveness of a physical activity program (van Sluijs et al., 2007). In our study, all GOTR participants, but one who completed the study had at least a 75% participation rate in GOTR, attending 15 or more out of the 20 practice sessions offered within a single season.
CHAPTER 6

CONCLUSION

The importance of physical activity for optimal health is not disputed. Physical inactivity has been implicated as a contributor to a variety of chronic conditions, among them osteoporosis. While physical activity is essential for all individuals at every age, research supports that physical activity exposure prior to adolescence may provide the greatest potential to influence lifelong skeletal health. Given that osteoporosis is more prevalent among women, increasing physical activity among pre-adolescent girls is critical. And as such, it is imperative to identify specific activities or programs that are effective at increasing physical activity and that have been shown to positively impact bone health. This study examined whether a popular running-based program for young girls provided an opportunity for young girls to engage in levels of physical activity that support health and whether participation in this program was associated with enhanced bone health. Our results suggest that the GOTR program is effective at increasing MVPA levels during the time that girls are enrolled. Further, we found that participation in GOTR is associated with positive changes in BMC at the femoral neck and intertrochanteric regions of the hip. We know that adolescence presents a “window of opportunity” to optimize bone growth and development, yet this is also a time when physical activity levels among girls are observed to decrease. Developing programs which provide an opportunity for young girls to be active before they reach this critical juncture may help to offset the decrease in MVPA or perhaps even promote an increase in MVPA, and in turn optimize skeletal growth. Combined, these results merit improved strategies to recruit and retain girls into GOTR and similar programs.

The question still remains as to whether or not BMC gains during growth and maturation persist into adulthood and whether optimizing these gains has a role in the prevention of chronic bone disease such as osteoporosis later in life. However, the acute effects of activity on bone are well documented (Fuchs & Snow, 2002; Gunter et al., 2008; MacKelvie et al., 2003; Petit et al., 2002). Specifically, we know high impact activities such as jumping performed several times per week are known to benefit the growing skeleton. While we know increased levels of physical activity in children in general are associated with greater bone outcomes (Janz et al., 2004; Janz et al., 2007), the exact dose and type of activity
needed to continue to promote these outcomes across the lifespan is unknown. Whether or not running performed regularly and at a specific intensity in young children for example, can have the same effect on the skeleton as jumping has not been established. Our data suggest that GOTR participation may provide acute benefits to bone. However, future studies examining the influence of GOTR on physical activity and bone outcomes beyond 9-months are necessary to gain a better understanding of the program’s true effects.

With more research exploring the potential benefits associated with participation in GOTR, more communities may be likely to adopt and implement this program. Future studies should look to recruit a larger sample population and use multiple measures to quantify physical activity. Ideally, a randomized, controlled trial where girls are allocated to participate in either GOTR, a jumping protocol, or another community-based program that is not necessarily expected to influence skeletal health would be useful to fully understand the potential of this program to influence girls’ physical activity levels and skeletal development.
BIBLIOGRAPHY


APPENDIX
APPENDIX A

Sample Lesson Plan of the *Girls on the Run* Program

**Introduction (20 minutes):** Name game, review of previous session’s lessons, introduction of lesson for current session, activity, discussion of activity objectives

**Warm-Up (20 minutes):** Activity related to lesson providing low intensity PA, stretch, discussion of activity objectives

**Workout: (20 minutes):** Activity related to lesson providing moderate intensity PA, stretch, discussion of activity objectives

**Wrap-Up (15 minutes):**
Cool down and stretch, discussion of entire lesson, closing cheer, snack.