Bone Strength Assessment in Martial Artist Brick Breakers

A Thesis Submitted to the College of

Graduate Studies and Research

in Partial Fulfillment of the Requirements

for the Degree of Master of Science

in the College of Kinesiology

University of Saskatchewan

Saskatoon

By

Blair F. Healey

Summer 2010

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Abstract

INTRODUCTION: Bone strength plays an important role in reducing fracture risk. Osteoporosis is a condition as a result of low bone strength and is characterized by deterioration of bone tissue and loss of bone mass, leading to increased fracture risk ("Osteoporosis Canada", 2009). Impact loading through exercise has been well established as an activity to maintain and improve bone health (Schwab & Klein, 2008), with high impact activities eliciting a larger response in bone adaptation over low impact activities (Daly, 2007; Guadalupe-Grau, Fuentes, Guerra & Calbet, 2009). The high impact loading of brick breaking within martial arts should be of sufficient magnitude to elicit bone adaptation. PURPOSE: The overall purpose of this study was to examine if the bones of the loaded arm among martial artists with brick breaking experience appear to have adapted to the high impact loading of brick breaking. In order to address this the specific objectives are (1) determine if brick breakers have a larger percent side-to-side difference over age and size matched controls in bone strength index (BSI_c) at the 4% radius and 6% ulna, SSI_p at the 65% ulna and 50% humerus, and grip strength. (2) Determine if the total number of lifetime brick breaks is correlated with percent side-to-side difference in strength strain index (SSI_p), a measure of torsional strength, at the 50% humerus. (3) Confirm the load experienced during the brick break can be considered high impact (>4 X body weight). METHODS: Male brick breakers (N=13, mean age 31.1 (SD 10.5) yrs) and their age and size matched controls (N=13, mean age 31.7 (10.8) yrs) had measurements of SSI_p on both arms mid-humeri using pQCT (Stratec XCT2000). Brick breaking history was obtained by questionnaire. SSI_p between arms in both groups was assessed by dependant t-tests and percent side-to-side difference (bilateral asymmetry) between groups was assessed by independent t-test. Brick breaking force was assessed with 9 black belt participants performing a total of 13 brick break attempts by striking a standard stack of 8 patio blocks on a force platform. RESULTS: Dominant humerus SSI_p was 7.7% (124 mm^3, $p<0.001$) greater in brick breakers and 5.3% (96 mm^3, $p=0.023$) greater in controls. Side-to-side differences did not differ between the groups (mean difference of 2.4%, $p=0.333$). Brick breaking history of total breaks was moderately correlated ($r=0.73$, $p=0.002$) with torsional bone strength side-to-side difference. Peak vertical forces ranged from 2075 N to 4496 N (mean: 2960 N). CONCLUSION: Brick breakers bone strength in the loaded arm seemed to have not adapted to high impact forces. However, the association between total number of breaks (impacts) and side-to-side strength difference suggests that a minimum number of loading sessions may be required before significant strength adaptation occurs. The forces experienced during a brick breaking strike approach forces that are considered high impact in lower body activities.

Acknowledgements

First and foremost, I would like to acknowledge my supervisor Dr. Karen Chad. Karen, thank you for your time, guidance, support, and encouragement. I am very grateful for all your efforts over the past couple years along with all the opportunities for growth and learning. Thank you for your continued encouragement and support as I prepare to move into a new chapter of my life. I would also like to acknowledge my committee members Dr. Cathy Arnold, Dr. Joel Lanovaz, and Dr. Saija Kontulainen. Thank you for your time, advice, guidance, enthusiasm, and availability throughout this project. Joel, a special thank you for the opportunity to expand this project to include biomechanic analysis and all the extra hours spent in the lab.

Thank you to all members for bringing all of your unique expertise together into this project, for always having an open door, and for your positive encouragement throughout. You have made this such a great experience for me and I truly feel blessed to have met and worked with such positive people.

Dedications

I dedicate this Master’s thesis to my family. Mom and Dad, you have always encouraged and supported me through everything I’ve done. You’ve taught me to stay positive and to believe in myself, “Think you can or think you can’t, either way you will be right.” (Dad, 1982 onwards). Older sister, I’ve enjoyed the novelty of going through graduate studies together, I admire your commitment and dedication to your work while maintaining family balance. My soon to be wife, thank you for saying “yes” and thank you for saying that you will support me in whatever I decide to do.

I love you all.

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Operational definitions

Bone strength: Mechanical competence of bone. Determined by material and structural properties.

Material composition: The mineral and type I collagen content of bone determining bone strength in terms of compressive and tensile force.

Structural composition: The size, shape, and architecture of bone determining bone strength in terms of design and arrangement.

Bone health: Referring to the presence or absence of deficits or diseases related to bones ability to maintain, grow or adapt.

Polar section modulus: A measure that takes into account the bone at the furthest point away from the neutral axis, and is used in calculations to estimate bones ability to resist torsion and bending force.

Bone mineral content (BMC): Total grams of bone mineral (hydroxyapatite) within a given site.

Bone mineral density (BMD): Grams of bone mineral per unit of area or volume.

Bone mass: Refers to the quantity of bone and is represented by BMC.

Cortical bone: Forms the dense outer shell of bone and is predominantly present in the shaft of long bones, providing structural strength.

Trabecular bone: Sometimes referred to as 'spongy' bone made up of a network of plates and rods (trabelculae) resisting loads from multiple directions; found at the ends of long bones and within other bones resisting compressive loads such as the vertebrae.

Epiphysis: The ends of long bones where trabeculae is found.

Osteoblasts: Bone cells responsible for the formation of bone matrix.

Osteocytes: Mature osteoblasts buried within bone matrix, no longer responsible for bone formation but rather for means of communication of applied loads.

Impact loading: An applied force in which initial contact between objects occurs over a short period of time.

Torsion loads: Twisting force along the neutral axis of bone.

Minimum effective strain (MES): The minimum amount of deformation needed to stimulate a change in bone mass or geometry.

Site-specific modeling and remodeling: Bone adaptation occurring in the same location the applied load is resisted within the bone.

Microstrain: The unit used to measure deformation of bone from an applied load.

Estimated bone strength: Derived from cross-sectional images and mathematical formulae to obtain a prediction of bone's ability to resist forces.

Cortical density: Grams of bone mineral per unit of volume specific to the cortical bone.

Cortical area: The total space taken up by cortical bone, represented by mm^2.

Bone Strength Index (BSI): Index of compressive strength used at distal sites.

Strength strain index (SSI): Index of torsion and bending strength used at shaft sites.

Percent side-to-side difference: The amount the dominant arm is greater compared to the non-dominant arm for a given measure, represented by a percent.

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CHAPTER 1

SCIENTIFIC FRAMEWORK

1.1 Introduction

Bone strength is an important determinant of fracture risk (Sambrook, Cameron, Chen, Cumming, Lord, et al., 2007). Given that bone is a metabolic tissue, adapting to environmental changes, there is potential to improve bone strength or at least prevent degeneration in bone health. This literature review will outline how degradation in bone strength is currently affecting our society, how bones adapt to environmental stimuli such as exercise, and where research has brought us to date. This literature review will then conclude by introducing how the activity of brick breaking in martial arts can bring research closer to understanding more specific exercise mechanics leading to improved bone health.

1.2 Literature Review

1.2.1 Osteoporosis and Bone Health

Osteoporosis, as defined by low bone mineral density (BMD), leads to bone fragility and increased risk of fracture ("Osteoporosis Canada", 2009). This disease is most common in older populations with Canadian statistics showing osteoporosis to affect one in four women and one in eight men over the age of 50 ("Osteoporosis Canada", 2009). Given that the proportion of older people in our population is expected to increase so too is impact of osteoporotic fractures in our society. The financial and human cost of osteoporosis is already significant (approximately 1.3 billion dollars spent annually in Canada and is the leading cause of hip fractures in older adults) and with the increasing older population this is expected to rise ("Osteoporosis Canada", 2009). It is well known that bone mass, in terms of size and content, increases throughout our growing years of childhood and adolescence, plateaus during adulthood, and begins to decrease during late adulthood. Adaptations in bone can still occur during adulthood, however the physiological response is not as great (Warden & Fuchs, 2009). Therefore, the growing years represents the ‘window of opportunity’ when physical activity can have the largest effect in preventing osteoporosis (low BMD) later in life. Recently, the idea of low BMD being the main predictor of fracture risk has been challenged. We are now beginning to understand that there are other important factors, such as material composition and geometric structure that contribute to bone strength (Mori, 2008; Ruppel, Miller, & Burr, 2008, Seeman, 2008). However, it still holds true that those at highest risk of fracture are the elderly; and with this population, the immediate strategy to reduce fractures is by reducing the risk of falls causing fractures (Shwab & Klein, 2008). Although immediate focus in elderly populations is on fall prevention, continued research focused on developing and maintaining bone strength earlier in life, through the mechanical loading of exercise, still holds important relevance for long-term prevention of degenerative bone strength.

1.2.2 Bone Adaptation to Mechanical Loading

1.2.2.1 Mechanostat Theory

Bone strength as defined by structural integrity and organization, is an important factor determining fracture risk (Gupta & Zioupos, 2008). Fundamental to understanding the strength of any material property is the concept of stress, strain and stiffness. Recent work (Bailey & Brooke-Wavell, 2008; Kontulainen, Hughes, Macdonald, & Johnston, 2007; Frost, 2003) based on Frost’s Mechanostat theory suggests bone resorption and formation is regulated by strain levels (Bailey & Brooke-Wavell, 2008). For example, if strain level exceeds a set point for minimum effective strain for remodeling new bone is formed. These set points are affected by changes in factors such as mechanical load (strain), hormone levels and nutrition. It is the response to these set points by mechanical loading that is referred to as the mechanostat theory (Frost, 2003). The specific method in which this process occurs is what determines bone strength by altering the structural and material density. Evidence suggests mechanical loading may have the ability to increase structural strength by improving the shape, size, and architecture of bone (Turner, Warden, Bellido, Plotkin, Kumar et al., 2009; Turner & Roblng, 2004; Kontulainen et al., 2007) and to improve material composition by increasing the degree of BMD (Ward, Roberts, Adams and Mughal, 2005; Dyson, Blimkie, Davison, Webber and Adachi, 1997). As stated by Ego Seeman (2008), “Structure determines loads that can be tolerated but loads also determine structure” (p. 1).

Prior to explaining Frost’s mechanostat theory, bone modeling and remodeling should be defined. Turner (1998) explains bone remodeling as a balance between old bone resorption and new bone formation under normal loading patterns. In a sense, a state of homeostasis that maintains the quantity and quality of bone needed for normal loading. However if the normal loading decreases beyond a certain threshold, bone resorption will exceed bone formation. The reverse also occurs when normal loading increases beyond a certain threshold, causing bone formation to exceed bone resorption. It is this point of bone formation exceeding bone resorption that defines bone modeling, which results in an increase of bone mass and size.

As mentioned earlier, Frost's mechanostat theory implies that bone has various set points determining the sensitivity of bone response to mechanical loads (Frost, 2003). These set points or thresholds are often expressed in microstrain (με) units and are referred to as minimum effect strain (MES). The value for each threshold can vary among individuals. Three MES thresholds should be considered: remodeling MES, modeling MES, and repair MES. (1) The Remodeling MES: strain levels below this threshold result in net bone loss and strain levels between this threshold and the Modeling threshold result in bone being maintained from normal physiological loading; (2) Modeling MES: strain levels above this threshold and below the Repair threshold result in a net gain of bone from overloading; and (3) Repair MES: strain above this threshold results in bone microdamage and it is suggested that this range is where largest increases in bone mass occurs as a result of repairing the microdamage caused (Bailey & Brooke-Wavell, 2008; Frost, 1983). It is the latter of the three MES thresholds which can provide the mechanical strain to increase bone mass. These three levels of MES mentioned above support the evidence from research that higher magnitude loads are associated with greater gains in bone mass. However, this theory is restricted to explaining only the magnitude of the deformation and not rate, frequency, type, or distribution of the load. Therefore, it should be noted that the magnitude of the load is not the only factor to be considered to increase bone strength.

1.2.2.2 Rate of Loading

The rate at which loading occurs has also been suggested to play a role in adaptive bone remodeling or modeling. Higher load rates have been associated with higher bone response in animal studies (Turner et al., 2009). A situation where high loading rates occur is during high impact. This suggests that impact loads would act as a high loading rate to stimulate a response in bone adaptation. As the loading rate increases so too does the stimulus for a response in bone turnover and formation, whereas slower loading rates do not have such an effect. Thus, exercises that apply forces to bones over a shorter period of time potentially have a larger benefit for gains in bone strength than a force experienced over a longer period of time. For example a rebounding jump would impose a force over a shorter period of time compared to a squat, and would therefore theoretically result in greater gains in bone strength. How these bone changes occur from high magnitude forces applied over short periods of time, can be explained by the process of mechanotransduction.

1.2.2.3 Mechanotransduction

Mechanotransduction is the process of communication of mechanical forces to bone cells in order to mediate bone adaptations. When a mechanical force of sufficient magnitude is applied to bone, the result is an elastic deformation in compression, bending, or torsion of the bone. This temporary elastic deformation creates movement of the extracellular matrix causing a fluid shear force to occur. The fluid shear force is: (1) sensed by osteocytes and osteoblasts, which then lead to an alteration in gene expression for bone adaptation; and (2) exposes osteoblasts to the extracellular matrix providing needed nutrients for new bone formation (Tanaka, Sun, Roeder, Burr, Turner & Yokota, 2005; Knothe, Knothe & Niederer, 1998). With a fluid shear force occurring at specific locations in response to mechanical loads, this suggests that changes may be site-specific.

1.2.2.4 Site-Specific Bone Adaptation

Site-specific modeling and remodeling is suggested to be one of the mechanisms in which bone adapts to specific mechanical stimuli. Bone responds to mechanical loading with only the affected region of an individual bone adapting when sufficient microstrain is experienced (Warden, 2006). This agrees with Frost’s mechanostat theory, mentioned earlier, but suggests that it is site specific. This process is targeted specifically to the damaged region of bone and occurs following incidents of microdamage. The process of site-specific remodeling occurs by the initial microcracks/microdamage, followed by programmed cell death (aptosis), and then by modeling of the tissue to provide adaptations for the new mechanical environment (Burr, 2002). Site-specific changes have been seen with exercise interventions studies. For example, Adami, Gatti, Braga, Bianchini, and Rossini (1999) found increases in the distal radius of 2.2%, 2.8%, and 3.1% for volumetric cortical density, cortical cross sectional area and cortical bone mineral content (BMC) after a 6 month exercise program focused on stressing the wrist with weight training and volley ball. Winters-Stone and Snow (2006) also found a 12 month exercise program produced site-specific changes in areal bone mineral density (BMD) with a 1.3% BMD gain in lumbar spine in an upper-body weight training group compared to a 0.3% BMD gain in a lower-body weight training group. Site-specific remodeling has been suggested to occur by two processes: (1) osteocytes being able to detect changes in localized strain; and (2) mechanical forces disrupting the communication network between osteocytes resulting in differentiation or proliferation of surface area (Burr, 2002). The evidence of site-specific modeling for bone adaptation coinciding with formation of new tissue in specific areas suggests that the quality (size, shape, and architecture) of bone may be more relevant in determining bone strength rather than solely the quantity of bone. This is highlighted by Warden, Hurst, Sanders, Turner, Burr and Li (2005) finding small changes in bone size and structure (<2-fold) led to a large increases in bone fatigue resistance (>100-fold).

1.2.2.5 Architecture and Material Composition

Simply having a greater bone mass does not indicate an increase in ability to withstand forces efficiently. Rather it is a combination of the manner in which the mass is arranged in shape and architecture along with material composition that is a stronger determinant of bone strength (Kontulainen et al., 2007; Ruppel et al., 2008). The material composition of bone refers to the type I collagen imbedded with calcium hydroxiapatite mineral (Kontulainen et al., 2007). These structural and material components are also said to be under mechanical regulation adapting in accordance to the loads applied to the bone (Kontulainen et al., 2007). The material composition of bone will be different between newly formed bone and older bone and will therefore have different abilities to resist force (Currey, 2003). Older more mineralized bone tissue may have a higher density providing a stiff bone, yet bone with low mass and when faced with resisting forces may prove to be more brittle than newer softer bone. However, younger less mineralized bone has been shown to be softer, more flexible and ultimately weaker than older more mineralized bone (Currey, 2003). This difference is present given that the newly formed bone may have a lower density, as areas of remodeling may be more porous due to active sites of resorption and formation (Kontulainen et al., 2007).

The structural layout of bone tissue is vitally important in determining bone strength. In the shaft of a long bone, the greater mass accumulated or distributed away from the neutral axis will result in a stronger resistance to bending and torsional forces (Daly, 2007; Kontulainen et al., 2007). Keeping in mind that the shaft is not a perfect cylinder, the geometry of the bone can indicate different ability of bone at a particular location to be more able to resist forces in certain directions over others (Kontulainen et al., 2007). The trabecular aspect of bone located at the epiphysis of long bone is indicative of the ability to resist compressive loads by being more porous and composed of a matrix of plates and rods with a higher capacity for flexibility during compressive loads (Kontulainen et al., 2007). The matrix of plates and rods also transfer part of this compressive load to the cortex to assist in withstanding the applied forces (Ruppel et al., 2008). This concept of structural and material bone strength has lead to the effort of estimating bone strength by examination of the architectural design and material compostion of bone.

1.2.2.6 Suggested Mechanisms for Bone Response

Much of the physiological theories described above have been supported by exercise based studies. To date, researchers have observed that certain mechanisms, such as intensity, frequency, and stress type have more of a bone response over others. Warden (2006) points out a positive correlation between increase in frequency being associated with increase bone stimulation. Interestingly however, Daly (2007) suggests that few loading cycles are required to observe an increased bone response. This suggests that few loading sessions are required to have bone adaptation and that there is a dose response effect with the number of loading sessions. Andreoli et al. (2001) suggested that the intensity of the load is more important than the duration of the stimulus. Vainionpaa, Korpelainen,Vihriala, Rinta-Paavola, Leppaluoto et al. (2006) also point out that the frequency of the session is more important than the duration of the session. Schwab and Klein (2008) note that short repetition and high impact have led to beneficial bone changes. Finally, reviews by Bailey and Brooke-Wavell (2008) and Guadalupe-Grau et al. (2009) emphasize beneficial effects comes with rapid application, high magnitude and dynamic in nature for increasing bone mass and improving bone strength. In summary, we are looking for an exercise stimulus that is high in magnitude, rapid in application, and low in repetition, with a high frequency not being a requirement. Even though these stimuli have been suggested in the literature as effective means to elicit bone adaptation, minimal research has been done to examine low repetition high impact forces in the upper body.

As of yet no specific values are suggested for actual impact magnitude, number of training sessions, and number of repetitions for use in prescription. This type of information would be useful in understanding the mechanisms behind bone adaptation to mechanical loading. Given this, it is a viable area of exploration requiring more research and one that has been suggested recently in the literature (Bailey & Brooke-Wavell, 2008; Daly, 2007).

1.2.3 Bone Adaptation to Exercise

1.2.3.1 Impact Activities and Bone Response

Exercise has been well established as a common intervention capable of enhancing or maintaining bone strength as prevention and treatment of osteoporosis (Schwab & Klein, 2008). Various researchers have observed that different sports and physical activities have different effects on bone properties, with the gains in bone strength properties being focused on high impact activities. For example, Nikander, Sievanen, Uusi-Rasi, Heinonen, and Kannus (2006) compared the estimated bone strength of hurdling, soccer, volleyball, and racquet athletes against swimming athletes finding athletes from all the above disciplines to have greater section modulus in their non-dominant tibia compared to the swimming athletes at the distal (43.9%, 43.5%, 36.7% & 27.1%, respectively) and shaft sites (31.6%, 23.8%, 18.1% & 13.4%, respectively). Nikander, Sievanen, Heinonen, Karstila, and Kannus (2008) also compared estimated bone strength in mogul and slalom skiers to controls finding mogul and slalom skiers to have a greater polar section modulus in their non-dominant tibia then controls at the distal (42% and 61%, respectively) and shaft sites (30% and 13%, respectively). Also, Ward, Roberts, Adams, and Mughal (2005) compared estimated bone strength of gymnasts to controls and found gymnasts to have 9% greater strength strain index (SSI) in their non-dominant radial shaft compared to controls. These studies show the importance of impact activities such as hurdling, soccer, volleyball, racquets sports, skiing and gymnastics in having beneficial effect on estimated bone strength (Nikander et al., 2008; Nikander et al., 2006 & Ward et al., 2005). It has also been seen that gains made during exercise interventions have some ability to be maintained. Karinkanata, Heinonen, Sievanen, Uusi-Rasi, Fogelhlm and Kanna (2009) found, through follow-up of an exercise intervention in elderly women, that half of the gains made were maintained 12 months later in BSI at the tibial shaft. Although this study involved an older population, previous work by Pollock, Laing, Modlesky, O'Connor and Lewis (2006) also noted that past participation in artistic gymnastics, an impact sport, might be responsible for maintaining leg aBMD nine years later. Various review articles support these findings, highlighting the greater beneficial effects of high impact activity on bone strength properties over low impact activities (Bailey & Brooke-Wavell, 2008; Daly, 2007; Schwab & Klein, 2008). Lower body high impact activity has been defined as activities that generate ground force reactions greater than four times body weight (x BW) and low impact to be ground force reactions less than 2 x BW (Witzke & Snow, 2000).

To date, the majority of research on the benefit of high impact activity on bone strength has focused on lower body activities. This focus is based on the fact that hip fracture is the 2nd highest fracture occurrence in the world (Johnell & Kanis, 2006). In 1993 there were approximately 25,000 hip fractures in Canada and eighty percent of which were related to osteoporosis (“Osteoporosis Canada”, 2009). Mechanically, another reason for the focus on lower body impact research is that impact forces are typically higher given the support of bodyweight making it easier to be considered high impact loading of greater than 4 x BW (Witzke & Snow, 2000). Research is less prominent regarding impact activity of the upper body, especially in regards to high levels of impact.

The importance of upper limb bone strength is especially relevant as Johnell and Kanis (2006) report global statistics of forearm fractures to be the leading type of fracture within older adult populations with osteoporosis. Of an estimated 9 million osteoporotic fractures, incidence of forearm fracture leads with 1.7 million cases. With these results, it is important that the preventative effects of upper body impact training be quantified. Ward et al., (2005) compared 44 gymnasts to 42 controls and found various bone strength properties of the forearms to be greater among gymnasts compared to controls. Specifically, at the 50% shaft the gymnasts’ non-dominant radius was 9.2% larger in size, had an 8.2% greater cortical area, and a 13.6% larger strength strain index (SSI) compared to controls. At the 4% distal radius the gymnasts also had a 17% larger total BMD and 21% larger trabecular BMD compare to controls. Similarly, Dyson, Blimkie, Davison, Webber and Adachi (1997), compared 16 gymnasts to 16 nonathletic controls and found the distal radius in gymnasts to have stronger volumetric BMD than the controls (total=19%, trabecular=27%, & cortical=16%). Koh, Grabiner and Weiker (1992) and Daly et al, (1999) confirm the impact loads experienced during gymnastics to be what Witzke and Snow (2000) consider moderate to high impact loads with loading through the arms during back handsprings to be 2.37 x BW and 3.6 x BW. Even with these forces being below what is considered high impact, beneficial gains are still being made. Examining the sport of gymnastics allows examination of moderate to high impact upper body activity. However, one limitation of these investigations is that this model does not control for factors such genetics, nutrition and hormones. To illustrate the importance of controlling for these factors Mikkola, Sipila, Rantanen, Sievanen, Suominen, Kaprio et al. (2008) estimate genetics to account for 83% of the structural strength at the distal radius and Havill, Mahaneym, Binkley and Specker (2007) point out genetics can attribute 40-90% of the variability in aBMD, depending on skeletal site. In the case of gymnastics these factors could not be controlled for since a side-to-side comparison is not feasible given the bilateral nature of the sport. To control for these factors an ideal comparison model would be unilateral activities in which the dominant limb performs the majority if not all of the tasks involved in the exercise. Unilateral activities allow for comparison between the dominant (loaded) limb and non-dominant (non-loaded) limb within the same individual, thus controlling for genetics, nutrition and hormones.

1.2.4 Unilateral Activity as a Comparison Model

Earlier research has examined the effect of unilateral sports, such as tennis, on bone strength properties. In a cross-sectional study, Haapasalo, Kontulainen, Sievänen, Kannus, Järvinen et al., (2000) noted that bone of the dominant arm in tennis players had characteristics of stronger properties compared to the non-dominant arm and compared to controls, with larger values of bone mineral content (BMC), total area, cortical area, and indication of stronger material and geometric properties as assessed by BSI. In this case the percent side-side difference between tennis players and controls for BSI was 22.6% vs. 4.0% (p<0.05), respectfully. Similarly, Ducher, Tournaire, Meddahi-Pelle, Benhamou, and Courteix (2006) observed side-to-side differences in the arms of tennis players compared to age matched controls, with significantly higher BMC, BMD and bone area in the dominant arm of tennis players over controls at all sites. Warden, Bogenschutz, Smith and Gutierrez (2009) also found significant difference (p<0.01) of the polar SSI (SSI_p) in the humeral mid-shaft of baseball pitchers compared to controls, with percent side-side difference values of 41.7% vs. 11.5%, respectively. The strength of these studies is that by examining side-to-side differences of subjects, the researchers were able to control for factors such as genetics, hormones and nutrition. Although, these examples provide an ideal case for controlling the above factors, the activities studied may not be classified as high impact activities compared to that of gymnastics since the mechanical force sustained is primarily through muscle contraction as opposed to high loading forces from landing.

Since the research examining high impact upper body activities has been limited to bilateral type sports such as gymnastics and unilateral sports examined are limited to lower impact loads, a more ideal comparison model has yet to be examined. Examination of high impact, upper body, unilateral activities would enable side-to-side comparisons and would allow for accurate assessment of the effects of high impact activities on bone strength within the upper body limbs. This information would lead to further understanding of bone responses to various mechanisms thought to enhance bone strength.

1.2.5 Brick Breaking among Martial Artists

A sporting event that includes the aforementioned mechanisms of high impact forces, few repetitions, and rapid application is that of brick breaking within martial arts. Brick breaking is commonly a unilateral event of the upper body in competition, demonstration and practice within certain martial arts. This activity typically involves a single, unilateral impact, of high magnitude, with few loading cycles. To date, there is no other type of physical activity in the literature that provides this type of loading mechanism. Therefore, assessing if participants of this novel task have stronger bone characteristics in their striking arm compared to their non-striking arm will provide opportunity to further examine the above theories of ideal bone mechanisms. Troy and Grabiner (2007) estimated, via bone model, the forces needed to cause a fracture in the distal radius, scaphoid, and lunate; finding the highest fracture force to be 2830 N. When comparing this to the force experienced during a brick break we see that brick breaking forces can exceed this estimate by reaching forces as high 3600 N (Wilk, McNair, & Feld, 1983). It should be noted that the bone model created by Troy and Grabiner (2007) was based on a 53-year old female and typical martial artist brick breakers would be young adult males, who would likely be underestimated by this model. Regardless, this may suggest that the forces experienced during a brick break are close to the estimated fracture forces without actually sustaining a fracture. Muller, Webber and Bouxsein (2003) along with Myers, Sebeny, Hecker, Corcoran, Hipp, Greenspan et al., (1991) found the forces causing a coles fracture (distal radius) in cadavers was about 3200 N and 3700 N respectively. These estimated fracture loads are similar to the brick breaking loads reported by Wilk et al., (1983) with out sustaining any fractures. This suggests that these forces may be of enough magnitude to stimulate bone response or that these particular martial artists have already developed sufficient bone strength to withstand the forces experienced during a brick break. The important aspect of this brick-breaking model is that it combines low repetition, rapid application, high magnitude force (Wilk et al., 1983) and unusual loading compared to that of normal daily activity. This model is different than that of tennis by the loading mechanisms being fewer repetitions and higher magnitude of force. It is also different than that of gymnastics being that brick breaking is a unilateral sport providing the non-dominant arm as an ideal control comparison. Prior to assessing if the activity of brick breaking supports the ideal mechanisms for bone stimulation, an observational study would need to assess whether this population actually exhibit stronger bone properties in their striking arm compared to their non-striking arm.

The bricks commonly used are 2 X 8 X 16 inch concrete patio blocks, which are typically set up by being laid on a support system lengthwise with the greatest surface area facing up as the striking surface. When multiple bricks are stacked, steel hexagon nuts or wood spacers are placed at the corners or ends of each brick prior to laying the next one on top. This is done to provide a space between each brick. The loading mechanism applied to the brick or stack of bricks is a downward strike.

Research examining the characteristics of human brick breaking within martial arts is limited. There are no studies that have compared upper extremity bone properties of brick breakers to active individuals who do not participate in this activity. Wilk et al., (1983) and Vos and Binkhorst (1966) estimated the mechanical forces required to break a brick and examined the forces experienced when breaking bricks. Wilk et al., (1983) noted a mean peak value required to break one brick was 1900 N and the force observed with an unsuccessful break was as high as 3600 N. It was also noted that these striking forces were applied rapidly over a short period (3-5 ms). Vos and Binkhorst (1966) found the speed of the strike to be about 14 m/s and the force applied to be 568 N to break one brick and an unsuccessful break to be 873 N. However, it should be noted that the material composition of the bricks used by Vos and Binkhorst (1966) was said to be of baked clay, which is different than that of the concrete patio blocks used in the in Wilk et al., (1983) study. For comparison of forces to the sports of tennis and gymnastics mentioned earlier; a tennis backhand swing has been measured at 330 N (Wu, Gross, Prentice & Yu, 2001) and gymnastics back hand springs have been measure as high as 3.6 time body weight, or 2471 N for a 70 Kg person, (Daly, Rich, Klein & Bass, 1999). With this comparison we can see that brick breaking creates much higher forces compared to tennis and maybe in comparable ranges to gymnastics.

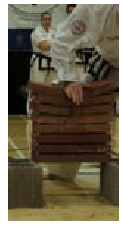
Given the dates of Wilk et al., (1983) and Vos and Binkhorst (1966), significant advancements have occurred in force data collection techniques. Also, given that these papers are the sole scientific articles examining the mechanics of brick breaking and the brick set up was different than that used by the martial artist population in the present study. Wilk et al. (1983) used less bricks in the stack and Vos and Binkhorst (1966) used bricks with a different material composition. With this, it is important that the force and speed experienced by the martial artist population for the present study be confirmed as high impact.

An aspect of variability within human brick breaking is the striking method used since there is no standardized method. A martial artist can strike the bricks by any method desired, however the common striking methods are with a hammer fist, palm heel, and elbow. The hammer fist method occurs with a tightly clinched fist striking the top brick with the fifth metacarpal, protected by abductor digiti minimi and opponens digiti minimi, Figure 1a. The palm heel method occurs with an open palm striking the top brick with the fingers hanging over the edge and forearm pronated, Figure 1b. The elbow strike occurs with the elbow flexed and shoulder medially rotated with the contact point occurring at the proximal surface of the ulna, distal from the olecranon, Figure 1c. Some less common brick strikes include a downward punch, striking with the knuckles of the fist; a knife hand strike, similar to the hammer fist but with an open hand; a downward elbow, striking with the olecranon shelf and shoulder externally rotated. Since the technique used is up to the martial artist, further methods not mentioned here may also be used. Another possible aspect of variability among this population is the rare use of the non-dominant arm. Even though the dominant arm is most commonly used there is nothing to stop a martial artist from occasionally using their non-dominant arm solely or in combination with their dominant arm.

Figure 1 Common brick breaking techniques

a. Hammer Fist

b. Palm Heel



c. Elbow

There are several other extraneous factors that may affect any side-to-side differences observed in this population such as: rest period between breaks, frequency of breaks, history of breaks with the non-dominant arm, training method, total number of successful and unsuccessful breaks, and muscular strength in the upper body. Rest period between breaks and frequency of breaks are important since bone is suggested to be an ever-changing tissue (Frost, 2003). If the rest periods between breaks are too long with no means of maintaining possible gains, a side-to-side difference may not be present. History of breaks with the non-dominant arm must be considered since high levels of activity could negate the purpose of the side-to-side comparison model (Bailey & Brooke-Wavell, 2008). How one trains for these high impact loads may provide information into whether the observed differences are also related to the method of training. Specific questions regarding their training would also lend insight into how they can withstand the applied forces. Is the general nature of their martial art training sufficient preparation or do they train specifically for brick breaking? The total successful and unsuccessful brick breaks would be important information given that Wilk et al. (1983) indicate that unsuccessful brick breaks resulted in substantially larger forces than successful brick breaks, 3600 N vs. 2900 N, respectively. Since, the unsuccessful breaks may produce a greater force it could be argued that unsuccessful breaks may have an even greater bone response. The total number of breaks and frequency of breaking session should also be addressed to explore if subjects have had enough exposure to the stimuli of brick breaking or perhaps there is a number of repetitions that is too low to stimulate or maintain a bone response.

1.2.6 Influence of muscular strength

A muscular contraction results in an applied load to the bones connected to the contracting muscles, the stronger the contraction the larger the resulting load on the bone. With this, it is evident that muscular strength is an influential factor on bone adaptation to loading (Hasegawa, Schneider & Reiners, 2001; Kaji et al., 2005; Rantalainen et al., 2008). For this reason, muscular strength is an important factor to consider when assessing the influence of an impact activity on bone strength. Therefore, inclusion of a measure of grip strength would be important information to consider as grip strength scores have been seen as significant predictors of SSI_p of the radius (Hasegawa et al., 2001; Kaji, Kosaka, Yamauchi, Kuno, Chihara & Sugimoto, 2005). Collection of grip strength scores would lend incite as to whether the side-to-side difference in bone strength values are due to muscular strength differences or the impact force experiences from the actual task of brick breaking. All the above information on brick breaking history, training methods, and muscular strength should be collected and considered in the analysis in order to provide further explanation of results in either case of significant or insignificant findings.

1.2.7 Bone Assessment Tools

There are various tools that have been used to estimate bone properties, each with certain advantages and disadvantages. The choice of measurement tool depends on the specific site to be measured along with the type of bone properties desired. Three methods of bone assessment have been used most recently throughout research: dual energy X-ray absorptiometry (DXA), quantitative ultrasound (QUS), and peripheral quantitative computed tomography (pQCT) (Radetti, Rigon, Tonini, Tato, Bernasconi et al., 2006). In determining the side-to-side differences in martial artist brick breakers the desired tool will be required to distinguish between cortical (long) and trabecular (spongy) bone and to assess the bone's ability to resist various forces in specific sites of the forearm.

The QUS uses speed of sound waves to estimate bone mass and is most commonly used on the calcaneus. Schoenau, Saggese, Peter, Baronecilli, Shaw, et al. (2004) point out that QUS is useful for evaluating the quality of bone and can be used at peripheral sites. However, it does not have the ability to distinguish between cortical and trabecular bone nor the bone's ability to resist different forces.

DXA has been used by many studies to measure areal BMD and is the diagnostic tool for osteoporosis. According to Binkley, Ryan, and Bonny (2008) osteoporosis is diagnosed by an areal BMD *T*-score of less than -2.5 standard deviations compared to that of a normal young adult. Binkley et al., (2008) and Schoenau, et al. (2004) indicate that DXA is useful for whole body measures estimating general bone health, but is not preferred for assessing specific sites. This tool provides a 2 dimensional view, which allows for areal BMD but not volumetric BMD. DXA does not have the ability to distinguish cortical from trabecular bone, and is unable to measure surrogates of bone strength such as bone size and geometry (Kontulainen, et al., 2007).

More recently pQCT has been established to examine the three dimensional cross sections of bone structure and tissue properties (Radetti et al., 2006). The pQCT scans provide distinction between types of bone such as cortical and trabecular bone and their properties (Kontulainen et al., 2007). These properties, measurable by pQCT, include bone size, geometry and tissue densities, which have been shown to predict bone strength due to bending, torsional, and compressive forces (Kontulainen et al., 2007). The structural strength in bending and torsional forces can be measured by the section modulus, which takes into account the bone at the furthest point from the neutral axis. However, the section modulus is only indicative of the structural strength, not material strength. SSI takes into account both, the section modulus and the material densities, giving a measure estimating bending strength in the x- and y-axis (SSI_x and SSI_y) and torsional strength in the polar direction (SSI_p) (Kontulainen et al., 2007). SSI_p has been shown as a valid measure of torsional bone strength (Macdonald, Kontulainen, Khan & Mckay, 2007; Schiessl, Ferretti, Tysarczyk-Niemeyer & Willnecker, 1996). BSI also takes into account both the section modulus and material properties, and can be used to estimated bone at compressive sites with a higher amount of trabecular bone (Rittweger, Beller, Ehrig, Jung, Koch et al., 2000). SSI and BSI calculations are displayed in equation 1. With this, pQCT also estimates specific bone properties such as area and volumetric density for cortical and trabecular bone. With the ability to estimate bone strength through pQCT, researchers are able to investigate how different activities influence bone strength with increased accuracy. The pQCT would therefore allow for detailed assessment of peripheral limbs, providing an ideal assessment tool to examine limb differences in unilateral sport practitioners.

Equation 1 BSI and SSI_p calculations

$$BSI = \frac{(\text{Total Area})*(\text{Total Density})^2}{1{,}000{,}000} \qquad SSI_p = \sum \frac{r^2 * a \frac{CD}{ND}}{r_{max}}$$

r=distance of a voxel from center of gravity

r_{max} = maximum distance of a voxel from center of gravity

a = area of a voxel [mm2]

CD = measured cortical density [mg/cm3]

ND = normal physiological density (1200 mg/cm3)

1.3 Objectives and Hypothesis

The overall purpose of this study is to examine if the bones of the loaded arm among martial artists with brick breaking experience appear to have adapted to the high impact loading of brick breaking. In order to address this, the specific objectives are (1) determine if brick breakers have a larger percent side-to-side difference over age and size matched controls in BSI_c at the 4% radius and 6% ulna, SSI_p at the 65% ulna and 50% humerus, and grip strength; (2) Determine if the total number of lifetime brick breaks is correlated with percent side-to-side difference in SSI_p at the 50% humerus; and (3) Confirm that the load experienced during the brick break can be considered high impact. It is hypothesized that (1) there will be a greater percent side-to-side difference in BSI_c at the 4% radius and 6% ulna, SSI_p at the 65% ulna and 50% humerus in the brick-breaking group compared to the control group, but no difference between groups in grip strength; (2) Total number of brick breaks will be correlated with percent side-to-side difference in SSI_p at the 50% humerus; (3) The load experienced during a brick break will be considered a high impact force, exceeding the suggested magnitude of four times body weight.

CHAPTER 2

METHODS

2.1 Study Design

The research design involved cross sectional analysis of 26 participants, comparing the side-to-side differences of bone strength properties in the upper limbs. According to a power calculation (alpha: 5%, beta, 80%) based on Haapasalo et al. (2000) results of bending strength differences in the radius, 10 participants would be required per group (brick breakers & control group). Therefore 13 participants per group were recruited to ensure adequate number of participants reducing the risk of a type II error.

2.2 Participants

The brick-breaking participants were recruited from martial art clubs throughout the province of Saskatchewan and surrounding area by club contact and poster advertisements. The inclusion criteria for this group was: 1) male, 2) age 16 years of age or older, 3) a minimum of 12 months experience in breaking bricks and 4) currently training in martial arts. Since this activity has a low number of female participants, a female sample size large enough would be difficult to recruit. The use of 12 months experience was chosen since many interventions with positive results are about 1 year in length (Bailey & Brooke-Wavell, 2008). The exclusion criteria for the brick breaking group was: 1) current use of pharmaceuticals that impact bone metabolism such as calcitonin, bisphosphonates, para-thyroid hormone (Bailey & Brooke-Wavell, 2008; Rodan & Martin, 2000); 2) current or past dominant limb physical activity or work such as competitive racquet sports or occupations such as carpentry; and 3) presence of a past arm fracture at the site of measurement. The participants in the control group were healthy males 16 years or older, who were matched within 5% of height and weight and age within six months to each brick-breaking participant at entry (Gilsanz, Skaggs, Konvanlikaya, Sayer Loro et al., 1998). The exclusion criteria for the control group were the same as that of the brick-breaking group.

2.3 Procedures

2.3.1 Screening by Questionnaire

Following recruitment, the participants were asked to provide informed consent, followed by the completion of four questionnaires for the brick breakers and three questionnaires for the controls. The first questionnaire: Medication, and Bone Health Questionnaire was used to gather information on medication, bone health, special diets and mineral supplementation (Lorbergs, Jackowski, Bennet, Johnston and Kontulainen, 2008). Nutrition and medication both have influence on bone metabolism (Morgan, 2008; Ward et al., 2005) and therefore medication, special diets and mineral supplementation were assessed by this questionnaire. The second questionnaire, The 10 question Waterloo Handedness Questionnaire, assessed degree of limb dominance (Bryden, 1977). The third questionnaire, The Lifetime Total Physical Activity Questionnaire, was used to screen participants for the exclusion criteria of past dominant limb activity. This questionnaire has been shown to be reliable with test-retest correlation of 0.74 (Friedenreich, Courneya & Bryant, 1998). The Lifetime Total Physical Activity Questionnaire was designed to be implemented within an interview setting, however in this case it was given in the form of a written questionnaire and answers were reviewed with each participant by the examiner. Consideration of lifelong physical activity is also important to asses since it is well known that bone properties respond the greatest during the growing years (Daly, 2007). The forth questionnaire, Brick Breaking History, was only given to the brick breaking participants and was used to provide information in establishing total number of successful and unsuccessful breaks, frequency of breaks, rest period between breaks, history of non-dominant arm brick breaks, and preparation practice. This questionnaire has been developed by the researcher and was used in this study for the first time. This questionnaire was administered in fill in the blank and written form asking the participants to give the details of all past brick breaks (including date, technique, dominant and non-dominant arm used, and number of bricks broken per attempt), method of training used to prepare for brick breaking, type of martial art involved in and belt rank in each, and what type of brick they are familiar with breaking.

2.3.2 Anthropometric Measures

Following the completion of the questionnaires, the participant's standing height (cm) was measured to the nearest millimeter, shoeless, feet together, and heals against the wall. Weight (kg) was measured by weigh scale, shoeless and wearing indoor clothes only. This was followed by measurement of humeral, ulnar and radial bone lengths by a flexible tape measure, measured 3 times with the average of the closest 2 measurements used for the limb length (example: measurement 1 = 17cm, measurement 2 = 18cm, measurement 3 = 21cm; the value used would be 17.5cm). If all 3 measurements varied by the same amount, an average of all 3 measurements was used (example: measurement 1 = 17cm, measurement 2 = 18cm, measurement 3 = 19cm; the value used would be 18cm). Radial length was measured from lateral border of the head of the radius (proximal end) to the lateral border of the styliod (distal end). Ulnar length was measured from olecranon shelf to the ulnar styliod. Humeral length was measured from the border of the lateral epicondyle to the edge of the acromion shelf. Anthropometric measurements were performed according to the International Standards for Anthropometric Assessment (2001). All but one of the participants were measured by the same person.

2.3.3 Grip Strength

Following anthropometric measurements, participants were asked to perform 2 grip strength measures with each hand on a handgrip dynamometer (JAMAR®, hydraulic hand dynamometer, 5030J1) according to the Canadian Physical Activity, Fitness & Lifestyle Approach (2003) guidelines. This protocol begins with the participant standing with there arms relaxed at their sides followed by breathing in, bringing their hand away from their body with a straight arm by shoulder abduction, then breathing out and squeezing the handgrip dynamometer with maximal effort for 2 seconds. This procedure is then repeated with the other hand and then the entire process is repeated for the second measurement. Of the 2 measures obtained on each hand the highest score was used. Inclusion of upper body strength assessment, by way of grip strength, was included since grip strength scores have been significantly correlated with SSI_p (Hasegawa et al., 2001; Kaji et al., 2005) and to observe side-side strength differences between groups.

2.3.4 pQCT Measurement

The instrument used to measure bone properties was the pQCT, since it has been shown to accurately estimate bone strength in peripheral limbs (Kontulainen et al., 2007). Having an R^2 value of 0.8 for bending strength (SSI_y) (Kontulainen et al., 2007), and an R^2 value of 0.81 for both total content at the distal radius and cortical thickness in the radial shaft (Ashe, Khan, Kontulainen, Guy, Liu, Beck et al., 2006), the pQCT proves to be a valid instrument to use for this study. This instrument has the ability to measure area, density and mineral content of cortical bone (CoA, CoD, cBMC), trabecular bone (TrA, TrD, tBMC), and a combined cortical and trabecular bone for total bone (ToA, ToD, BMC). From these measures the pQCT can predict bone's ability to resist compressive forces by BSI and ability to resist torsional forces by SSI_p. The reliability of the pQCT operator for SSI_p at the ulnar and humeral shaft, distal radius and proximal ulna reported coefficient of variances of 4.3%, 4.2%, 6.8% and 7.4%, respectively. With these values the pQCT proves to be a functional, valid and reliable instrument for the purpose of this study.

The pQCT model used was the Stratec XCT 2000 with Stratec software version 6.00B. The pQCT operational settings for all measurement sites had scan thickness of 2.3 mm, voxel size of 0.4 mm, and a scan speed of 20 mm/sec. All sites scanned are represented in Figure 2. The radius was scanned by the pQCT at the 4% distal radius (Figure 3 b) to measure the compressive strength, as experienced during a palm heel strike. The 65% ulna shaft (Figure 3 b) was measure for SSI_p to estimate the strength resisting torsional force (Haapasalo et al., 2000; Eser et al. 2005). A scout scan was performed to obtain a view of the radial/ulnar carpal joint and the reference line for the forearm measurements was placed on the shelf of the distal radius (Figure 3 a). The 6% proximal ulna (Figure 4 b) was measured at the proximal end to measure compressive strength since this is a common striking area for brick breakers using the elbow strike. A scout scan was performed to obtain a view of the radiohumeral joint with the reference line placed on the proximal edge of the olecranon (Figure 4 a). The humeral shaft

(Figure 5 b) was measured at the 50% site to assess torsional strength (Warden et al., 2009; Haapasalo et al., 2000), as experienced in all three striking techniques. A scout scan was performed to obtain a view of the radiohumeral joint with the reference line placed on the distal edge of the humeral capitulum (Figure 5 a). Although a martial artist may have a preferred striking method, all four pQCT scan locations were included in anticipation that the brick breaking volunteers would have adequate exposure to all breaking techniques. According to procedures outlined by Lorbergs et al. (2008) the radial sites of 4% and 65% were used to distal radius and radial shaft to assess bone strength properties. Procedures outlined by Haapasalo et al. (2000) and Warden et al. (2009) used the humeral site of 50% to measure the humeral shaft. All sites were measured with the participant seated and his/her arm raised laterally in a supported extended position with the wrist pronated. Analysis of pQCT scans were completed with the outer threshold set at 280 mg/cm^3 and inner threshold set at 480 mg/cm^3. Contour mode 1 was used to determine total bone area. Peelmode 2 was used to separate total bone into cortical and trabecular bone using the inner threshold of 480 mg/cm^3. Cortical mode 4 was used to allow the operator to define the inner and outer thresholds. No filters were used. The same operator measured twenty-five of the twenty-six participants and one of the twenty-six participants was measured by a different operator. Inter-tester reliability has been shown to have adequate levels of reliability with the operator’s coefficient of variance values ranging from 0.9 to 7.7% (Sievanen et al., 1998). Prior to data collection, the pQCT operators had been trained on the measuring equipment by performing test re-test measures on 10 different subjects to gain accuracy and precision with the pQCT prior to commencing data collection. This protocol has been verified as adequate competency in obtaining pQCT measures (Lorbergs et al., 2008). The precision values were calculated by $\sqrt{(\text{Mean CV}^2)}$. Precision values for the primary pQCT operator indicated that the scans at the humeral shaft were most consistent with a precision value of 4.2 followed by the ulnar shaft (4.3), distal radius (6.8), and proximal ulna (7.4).

Figure 2 Visual representation of four sites scanned by pQCT

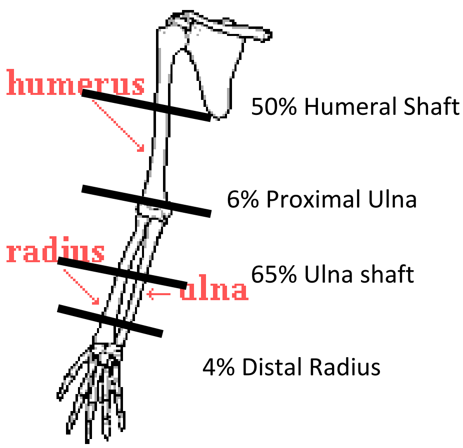
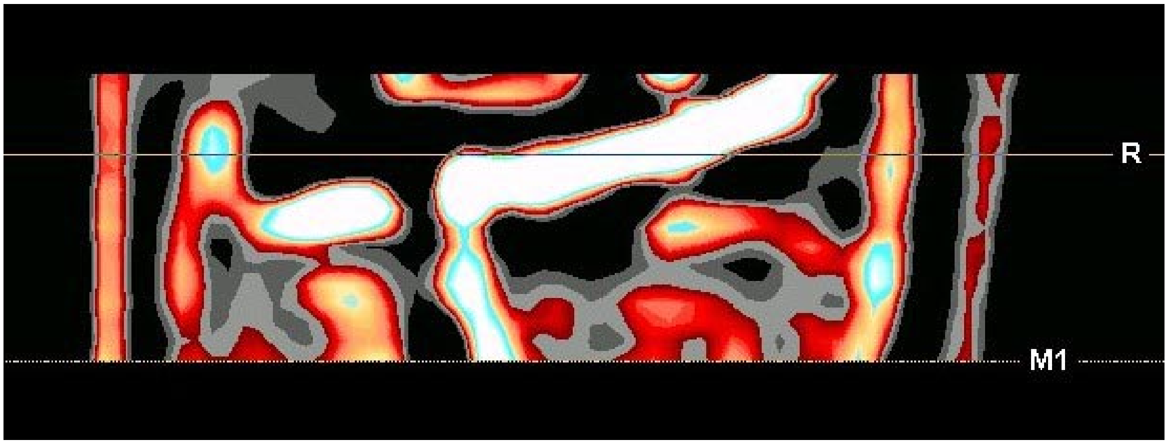


Figure 3 Forearm pQCT Scans

a. Radial scout scan: R=reference line, M1=measurement line



b. Actual Scan site at 4% Distal radius and 65% Ulna shaft

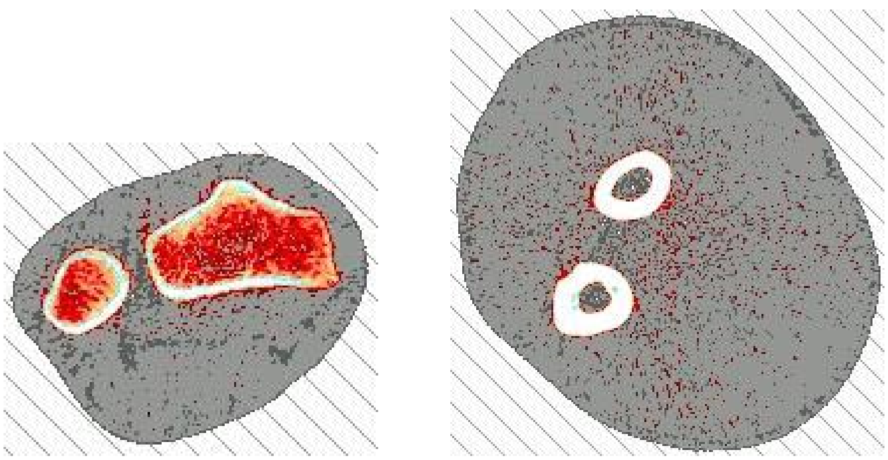
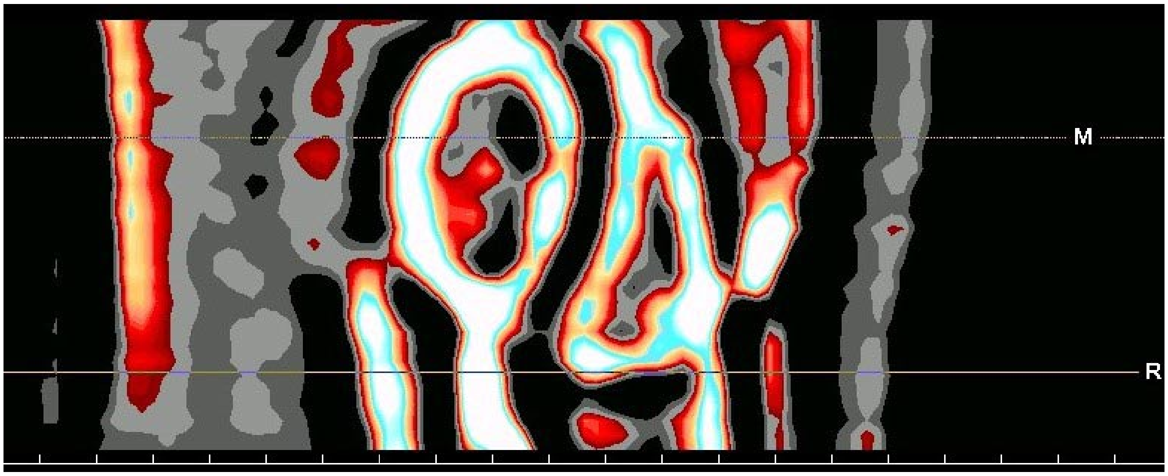


Figure 4 Elbow pQCT Scans

a. Ulnar scout scan: R=reference line, M=measurement line



b. Actual Scan at 6% Proximal Ulna

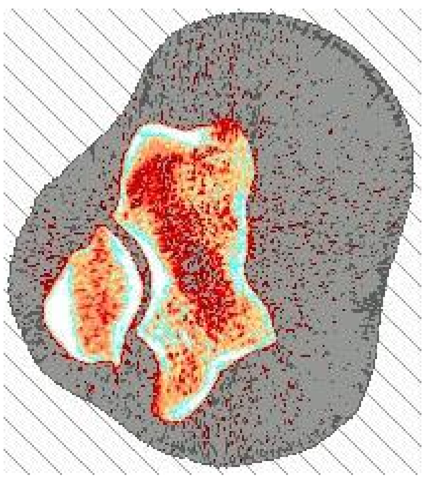
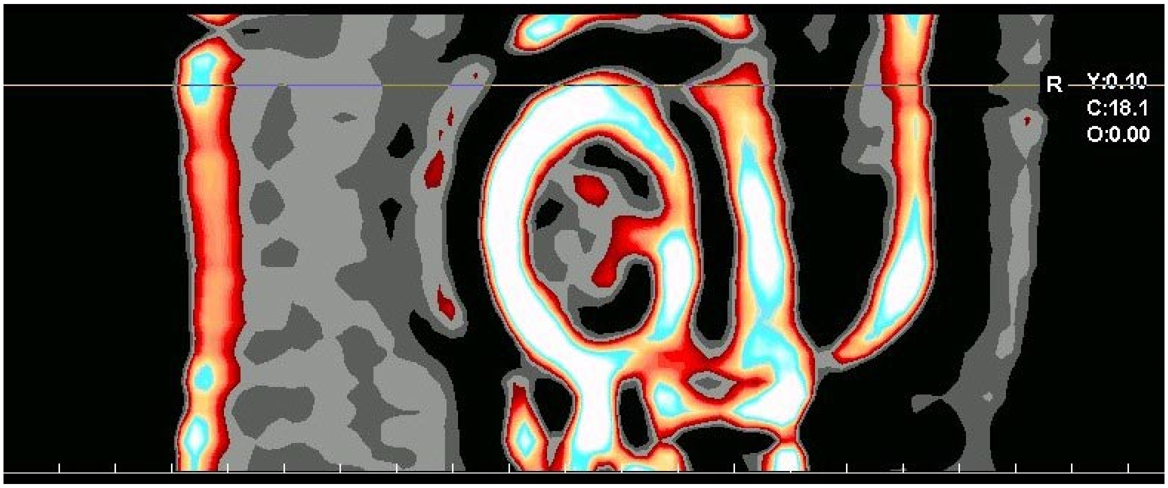
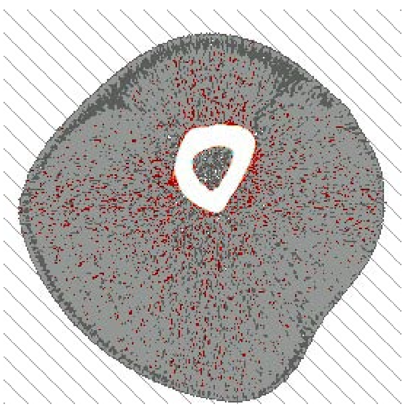


Figure 5 Upper arm pQCT Scans

a. Humeral scout scan: R=reference line



b. Actual scan at 50% Humeral Shaft

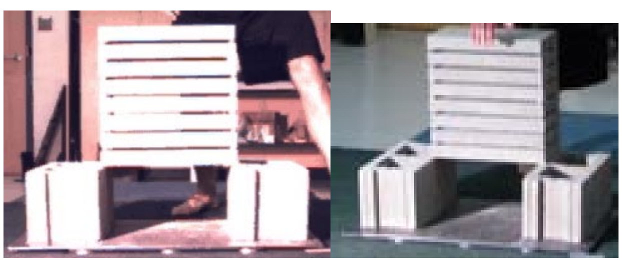


2.3.5 Force Assessment of Brick Breaking

2.3.5.1 Brick Stack Set up

Following pQCT measurement, for those brick breaking participants willing, analysis of brick breaking biomechanics were assessed to validate the magnitude and rate of the impact experienced along with information regarding muscular involvement during the brick break. The stack of bricks consisted of eight 2 X 8 X 16 inch concrete patio blocks (average mass of 6.52 kg each) stacked on top of each other with steel hexagon nuts placed at each corner used as spacers between each brick. Each brick was laid with the greatest surface area facing up with the top brick being the striking surface. Two cinder blocks, laid on their side, were used to support the stack of brick at each 8-inch end. Beneath the cinder blocks an additional raised metal plate was used to support the entire set up on the force plate (OR6-7, AMTI, MA), Figure 6. The brick set up was assembled on the force plate prior to the participant coming in. This force plate was a rectangular metal platform with force transducers that measure the three-dimensional forces applied to the plate's top surface. The force plate was embedded into the floor with the top surface level and flush with the floor. The data from this force platform provides information on the magnitude and direction of the force applied. Force data were recorded on a PC using an analogue to digital converter and were sampled at 4000 Hz.

Figure 6 Brick Set up



2.3.5.2 Brick Breaking Procedures

Once the above procedures were completed, the participants were instructed to use the breaking technique of their preference, given the freedom to prepare for the break as they normally would in competition or demonstration, and asked to give the researchers a 10-15 second warning prior to attempting the brick break.

Total time commitment from each participant was about 2.5 hours, which included questionnaires, anthropometric measures, grip strength assessment, bone assessment, and assessment of applied force during a break.

2.3.6 Analysis

2.3.6.1 Questionnaire Analysis

The Medication, and Bone Health Questionnaire and the Lifetime Total Physical Activity Questionnaire were used to confirm exclusion criteria. If participants indicated that they had a past fracture through the site of pQCT measurement, current use of medication affecting bone metabolism, or current or past major involvement in unilateral activities, they were excluded. The Brick Breaking History Questionnaire was analyzed by recording the total number of brick breaks performed with each technique (palm heel, first, elbow, or hammer fist) with either the dominant or non-dominant arm. No statistical analysis was used for these three questionnaires. The group mean scores from the Waterloo Handedness Questionnaire were compared between brick breakers and controls by means of independent t-test.

2.3.6.2 pQCT, Anthropometric, and grip strength Analysis

A one factor MANOVA was chosen as the initial analysis to assess differences between sites, with group as the factor and the side-to-side percent difference of radius BSI_c, ulna SSI_p, ulna BSI_c and humerus SSI_p were four dependent factors. However the results indicated that modification was required (see Results section 3.3). A one-tailed correlation was run between the total number of brick breaks and the percent side-to-side difference (Equation 2) of SSI_p at the 50% humeral site only. The 50% humeral site was chosen since it is mechanically affected by all styles of brick breaking. Dependent t-tests were used to compare grip strength scores between dominant and non-dominant limbs within groups, and independent t-tests were used to compare age, height and weight between groups.

The variables that make up BSI_c are total area and total density, and the variables that make up SSI_p are cortical area and cortical density. These variables should be examined for further discussion of the BSI_c and SSI_p results. Therefore, the raw values of each of these variables were examined between limbs of each group by dependent t-test. The side-to-side percent differences of these variables between groups were examined with independent t-tests. The analyses of these variables were included for exploratory purposes in the discussion section.

Equation 2 Percent difference calculation

Percent side-to-side difference = (Dominant – Nondominant) / Nondominant * 100

2.3.6.3 Force Analysis

Analysis of force between breaking styles was assessed by unpaired t-tests. The information gathered for this section included: number of participants, age and weight of participants, technique used, number of breaking attempts assessed, time to initial peak force, overall peak force, and peak force in relation to body weight. Age, weight, time to initial peak force, overall peak force, and force in relation to body weight will be the variables compared between breaking styles. Number of participants along with their age and weight was recorded for the reason that not all of the recruited brick breaking participants recruited for initial section of this study, pQCT measurements and questionnaires, volunteered to participate in this brick breaking section. Time to initial peak force and overall peak force was assessed to observe to what degree the impact force was rapid in application and high in magnitude. Peak force in relation to body weight was calculated for comparison to Witzke & Snow's (2000) definition of high impact force being greater than 4 x BW.

All statistical analyses were performed with the Statistical Package for Social Sciences software (SPSS 17.0 for Windows; SPSS inc., Chicago, IL, USA) and all tests used an α-level of <5% to be considered significant.

CHAPTER 3

RESULTS

3.1 Participants

A total of 13 male martial artists with brick breaking experience were recruited, all of which were eligible to participate based on the inclusion and exclusion criteria. A total of 16 age, height, and weight matched controls were recruited, 3 of which were not eligible due to considerable amount of past unilateral activity based on the Total Lifetime Physical Activity Questionnaire. Data from these 3 control participants was not included in any analysis.

3.2 Questionnaires

The Medication, and Bone Health Questionnaire reported that of the 13 brick breaking participants, 1 reported a past elbow fracture resulting in exclusion of data and in being removed from the MANOVA. In regards to special diets and mineral supplementation, 1 participant reported being a vegetarian and 4 participants reported taking multivitamins. No participants were currently taking pharmaceuticals that affect bone health.

The Waterloo Handedness Questionnaire reported no significant difference between brick breakers and controls in terms of degree limb dominance as assessed by independent t-test [t (24) = -0.034, $p = 0.937$]. Brick breakers were found to have a mean score of 14 ± 5 and controls to have a mean score of 15 ± 7. This indicates that both brick breakers and controls were fairly equal in the degree to which they used their dominant and non-dominant hand. Therefore, the results in side-to-side difference in estimated bone strength should not be skewed on account of one group being predisposed to more habitual dominant limb activity.

The Lifetime Total Physical Activity Questionnaire reported that all participants were free from current and past major participation in dominant limb physical activities, other than brick breaking for the martial artist group. Exclusion criteria was based on single limb household activities exceeding 7 hours per week for 4 months of the year, single limb physical activities exceeding 2 hours per week for 4 months of the year, and single limb occupational activities exceeding 8 hours per week for 4 months of the year.

From the brick breaking history questionnaire, it was apparent that there were two main groups, elbow brick breakers and palm heel brick breakers. Within the 13 brick breaking participants, 7 indicated that the elbow strike was their main technique used and 6 indicated that the palm heel strike was their main technique used. The self reported brick breaking history revealed brick breaking experience ranging from 2 to 49 breaks. Number of breaks and breaking style are displayed in Table 2. All brick breakers recruited reported their main martial art to be that of taekwon-do.

Table 1 Brick Breaks

	Brick Breaker Mean (SD)
Number of dominant arm breaks	14.7 (15)
Number of non-dominant arm breaks	1 (1)
Average time from last dominant arm break (yrs)	0.35 (0.28)
Average time from last non-dominant arm break (yrs)	5.08 (4.16)

-Data represented as mean (standard deviation)

Table 2 Summary of self reported brick breaking history

	Dominant Arm					Non-Dominant Arm				
Participant	Elbow	Punch	Palm	Hammer	**Total**	Elbow	Punch	Palm	Hammer	**Total**
1	24	3	12	10	49	0	0	2	0	2
2	2	0	0	0	2	0	0	0	0	0
3	1	1	22	1	25	1	0	3	0	4
4	2	0	37	0	39	1	0	0	0	1
5	11	1	6	5	23	0	0	0	1	1
6	0	3	0	0	3	0	0	0	0	0
7	0	0	4	0	4	0	0	0	0	0
8	0	0	9	0	9	0	0	0	0	0
9	4	0	0	2	6	0	0	0	0	0
10	8	1	1	0	10	0	0	0	0	0
11	0	0	6	1	7	0	0	0	1	1
12	2	0	1	2	5	0	0	0	0	0
13	0	2	7	0	9	0	0	1	0	1

-Values represent number of brick breaking attempts (successful and non-successful)

3.3 Modification in Statistical Analysis

Given that two separate groups emerged from the recruited brick breakers, the previously mentioned one factor MANOVA would not be an appropriate test for analysis. The one factor MANOVA was intended to examine brick breakers with experience in all three breaking techniques (hammer fist, palm heel, and elbow) and therefore having a load stimulus to all four measured sites (distal radius, ulna shaft, proximal ulna, and humeral shaft). However, brick breakers primarily using an elbow strike would not have an applied load to either the distal radius or ulna shaft and similarly those primarily using a palm heel strike would not have an applied load to olecranon shelf of the ulna (proximal ulna). In order to avoid splitting brick breakers into separate groups, the 4% radius along with the 65% and 6% ulnar scans were not included in any statistical analysis, leaving only the 50% humeral shaft for examination. Additional support for removing the proximal ulna and distal radius scans from analysis was that, as mentioned earlier, the precision values the pQCT operator obtained for the proximal ulna and distal radius sites were not as strong as the ulna and humeral shaft sites (7.4% & 6.8% vs. 4.3% & 4.2%, respectively), adding less reliability to the values. The ulna shaft was removed from analysis given that it would be the site specific area affected from the hammer fist strike and, from examination of the brick breaking history questionnaire, none of the brick breaking participants reported hammer fist strike as being their technique of choice. The humeral shaft was the remaining site affected by all three breaking styles. Given that one site was used for analysis, the following changes to the statistical analysis were made.

A dependent t-test was run for both brick breakers and controls comparing SSI_P at the humeral shaft between dominant and non-dominant arms to observe differences in raw values. An independent t-test was run comparing the percent side-to-side differences in SSI_P at the humeral shaft between each group to observe differences between groups.

3.4 Anthropometric Measures

Participant's age, height and weight are represented in Table 3. No significant difference was found between groups in age [t (24) = -0.147, $p > 0.05$], height [t (24) = -1.132, $p > 0.05$], and weight [t (24) = -0.004, $p > 0.05$] as assessed by means of independent t-tests. Recruitment of control participants were set out to be within 5% of height and weight and age within six months to each brick-breaking participant at entry. This was done in order to have control participants matched to brick breaking subjects within ranges coinciding with previous literature (Gilsanz et al., 1998). However, this proved to be a challenge in some cases. The mean age difference was 7.5 months with the largest age difference being 25 months. The mean height difference was 1.3% with the largest difference being 5.8%. The mean weight difference was 0.5% with the largest weight difference being 11.2%.

In requirement for pQCT measurements humeral length was measured. No significant difference between brick breakers and controls were found in humeral lengths. The statistic results were: dominant humerus [t (24) = 0.237, $p > 0.05$] and non-dominant humerus [t (24) = 0.405, $p > 0.05$], as assessed by independent t-test (and represented in Table 3).

Table 3 Participant Demographics & Anthropometry

Participant Demographics & Anthropometry			
	Brick Breaker Mean (SD)	**Control Mean (SD)**	***p*-Value**
Age (yr)	31.1 (10.5)	31.7 (10.8)	0.885
Height (cm)	176.6 (4.6)	178.9 (5.9)	0.269
Weight (kg)	90.5 (23.4)	90.6 (22.4)	0.997
Dominant Humeral length (mm)	341.2 (18.6)	339.6 (15.2)	0.969
Non-Dominant Humeral length (mm)	344.2 (12.7)	341.9 (15.7)	0.397

-Data represented as mean (standard deviation)
-*p*-value retrieved from independent *t*-test
-No significant differences between groups

3.5 Grip Strength

A significant side-to-side difference was found in brick breakers grip strength scores with the dominant hand being 6.9% (p = 0.009) greater than the non-dominant hand. No significant side-to-side difference was found in the controls with dominant hand only being 3.7% (p = 0.193) greater than the non-dominant hand. Group means are displayed in Table 4. No significant difference was found between brick breakers and controls in side-to-side differences, with mean side-to-side differences of 3.7 kg and 2.0 kg ($p = 0.39$), respectively. The significant difference found in the brick breaking group suggests that if a side-to-side difference in bone strength properties is found that an aspect of this difference may be due to an asymmetry in muscular strength.

Table 4 Side-to-side grip strength scores

	Dominant hand (kg)	Non-dominant hand (kg)	*p*-Value
Brick Breakers (Mean (SD))	57.4 (8.9)	53.7 (8.2)	0.009**
Controls (Mean (SD))	56.5 (9.0)	54.5 (6.9)	0.193

-Data represented as mean (standard deviation)
-*p*-value retrieved from dependent *t*-test
* = $p<0.05$ represents significant difference between limbs
** = $p<0.01$ represents significant difference between limbs

3.6 pQCT

The raw pQCT data of brick breakers and controls is represented in Table 5. In considering the primary objective of determining if a significant percent side-to-side difference in bone strength exists between brick breakers and controls, the independent t-test rejected the primary hypothesis. Significant side-to-side differences were found in both groups with dominant humeral SSI_p being 7.7% (124 mm^3, $p<0.001$) greater in brick breakers and 5.3% (96 mm^3, $p=0.023$) greater in controls. Although, brick breakers had a larger percent side-to-side difference than the controls, there was no significant difference between groups (mean difference of 2.4%, $p=0.333$). Individual differences displayed in table 6.

Table 5 Group means of raw pQCT data

	Brick Breakers				**Controls**				**Brick Breakers to control comparison**	
Measured Variable	**Dominant**	**Non-dominant**	**Side-to-side difference (%)**	***p*-value**	**Dominant**	**Non-dominant**	**Side-to-side difference (%)**	***p*-value**	**Difference (%)**	***p*-value**
SSI_p (mm^3)	1805.4 (197.1)	1681.5 (215.1)	7.7 (5.7)***	<0.001	1995.3 (382.4)	1899.8 (382.3)	5.3 (6.8)*	0.023	2.4	0.333
Cortical Area (mm^2)	342.8 (23.7)	326.8 (30.2)	5.2 (5.1)**	0.004	346.4 (47.1)	329.2 (50.9)	5.6 (5.3)**	0.003	-0.4	0.828
Cortical Density (mg/cm^3)	1045.8 (39.3)	1044.7 (56.2)	0.3 (5.7)	0.948	1044.9 (44.5)	1055.6 (44.3)	-1.0 (2.9)	0.215	1.3	0.468

* = Significant difference between dominant and non-dominant limbs ($p<0.05$)
** = Significant difference between dominant and non-dominant limbs ($p<0.01$)

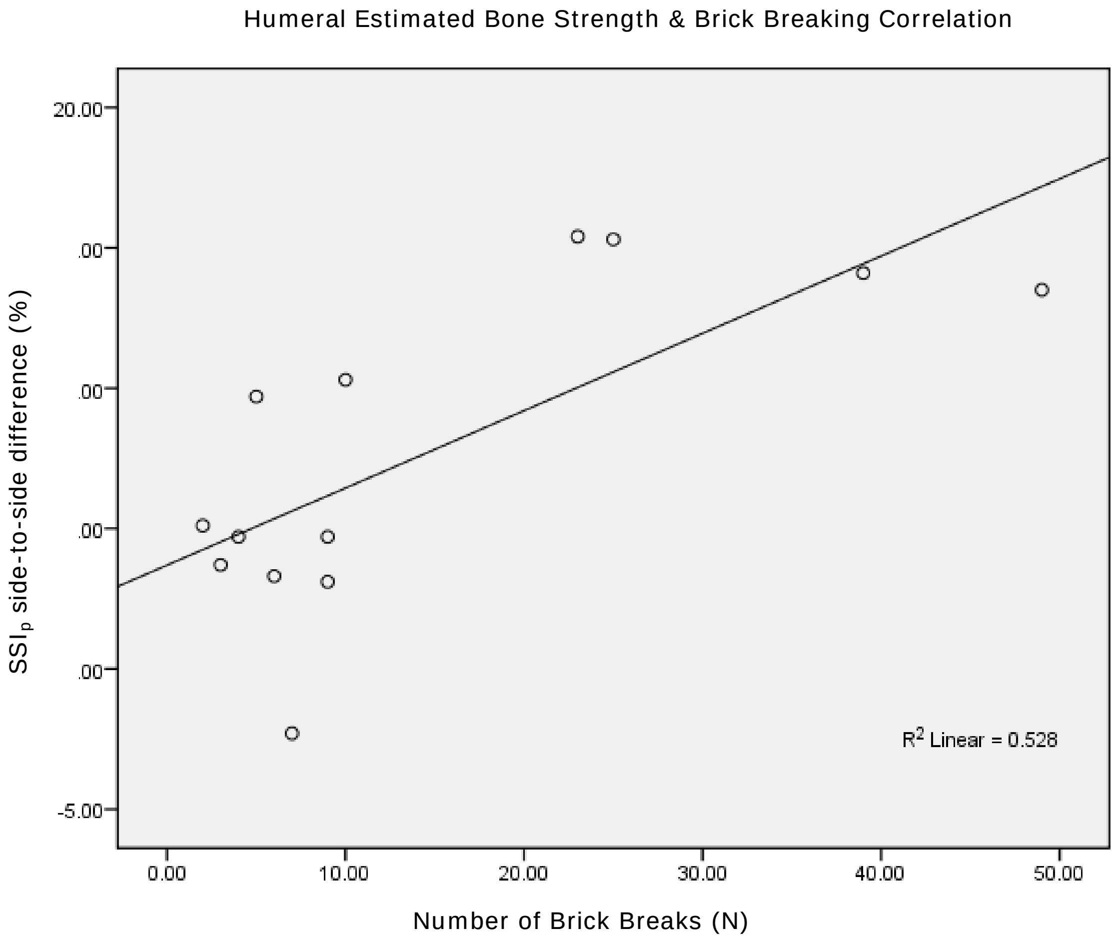
*** = Significant difference between dominant and non-dominant limbs (p<0.001)

Table 6 Individual SSI Scores at 50% humeral shaft

Participant	Brick Breakers			Controls		
	Dom-Arm (mm^3)	Non Dom-Arm (mm^3)	Difference (%)	Dom-Arm (mm^3)	Non Dom-Arm (mm^3)	Difference (%)
1	1808.7	1593.8	13.5	2386.5	2101.1	13.6
2	2157.8	2053.0	5.1	1879.8	1890.9	-0.6
3	1466.5	1271.5	15.3	1418.6	1458.7	-2.7
4	1817.9	1593.0	14.1	1696.3	1629.7	4.1
5	1883.6	1632.3	15.4	2018.5	2021.9	-0.2
6	1575.6	1519.8	3.7	1617.7	1473.8	9.8
7	1930.2	1843.9	4.7	2160.5	1891.6	14.2
8	1638.7	1589.0	3.1	2581.1	2500.4	3.2
9	1662.0	1608.8	3.3	2133.5	2287.6	-6.7
10	1660.8	1505.9	10.3	1777.8	1639.8	8.4
11	1864.9	1909.6	-2.3	2283.2	2000.5	14.1
12	1966.3	1793.0	9.7	1468.9	1341.8	9.5
13	2037.6	1945.6	4.7	2516.3	2459.0	2.3
Mean	**1805.4**	**1681.5**	**7.7**	**1995.3**	**1899.8**	**5.3**
SD	**197.1**	**215.1**	**5.7**	**382.4**	**382.3**	**6.8**

The secondary objective of determining if the total number of brick breaks are correlated with percent side-to-side difference in estimated bone strength property at the 50% humeral site displayed a moderate correlation, accepting the secondary hypothesis. The one-tailed correlation analysis between the total number of brick breaks and the percent side-to-side difference of SSI_p at the 50% site revealed a moderate pearson correlation [r (11) = 0.727, p < 0.05] (Figure 7). The R^2 adjusted indicated that 49% of the variance in the percent SSI_p side-to-side difference at the humeral shaft to be accounted for by the total number of brick breaks.

Figure 7 Humeral shaft SSI_p and total number of brick breaks correlation



-R^2 Linear = unadjusted variance

3.7 Brick Breaking Force

Nine experienced male black-belt level participants (mean: 30.8 yrs, 95.6 kg) made a total of 13 attempts to break as many bricks as possible by striking the top of a vertical stack of 8 standard concrete patio bricks. From table 2, the participants who participated in this section of the study were participants 1, 5, 6, 7, 8, 10, 11, 12, and 13. Of the 9 participants, 5 performed elbow strikes and 5 performed palm heel strikes.

Participant 5 performed two elbow attempts and two palm heel attempts. This participant's age and weight was included in both groups. Participant 7 performed two palm heel attempts. All other participants only performed one attempt. Of the 13 attempts, 6 were with an elbow strike and 7 were with a palm heel strike. From the independent t-tests there was no significant difference between groups in age (p = 0.785) or weight (p = 0.065). However, significant differences were found between breaking styles in time to initial peak force, overall peak force, peak force in relation to BW, and number of bricks broken. The time to initial peak force ranged from was 19.2% (p = 0.03) faster with the elbow strike compared to palm heel. The overall peak force was 30.1% (p = 0.047) greater with the elbow strike compared to palm heel strike. The peak force in relation to BW was 71.5% (p = 0.002) greater with the elbow strike compared to palm heel strike. The number of brick broken was 38.5% (p = 0.005) greater with the elbow strike compared to palm heel strike. Mean values are represented in table 7.

Table 7 Biomechanic Comparison between brick breaking styles

Striking style	**Elbow**	**Palm Heel**	**p-value**
Age (yrs)	29.50 (10.06)	31.46 (11.82)	0.785
Weight (kg)	77.80 (9.87)	108.30 (30.28)	0.065
Time to initial peak (ms)	4.79 (0.81)	5.93 (0.83)	0.030*
Overall peak force (N)	3391.78 (745.46)	2589.79 (542.73)	0.047*
Peak force (X BW)	4.51 (0.82)	2.63 (0.82)	0.002**
Bricks broken	6.33 (0.82)	4.57 (0.98)	0.005**

* = Significant difference between breaking styles ($p<0.05$)
** = Significant difference between breaking styles ($p<0.01$)

CHAPTER 4

DISCUSSION

The main finding of the present study was that brick breaker's bone strength in the loaded arm seemed to have not adapted as much as expected to high impact forces. However, the association between total number of breaks (impacts) and side-to-side strength difference suggests that a minimum number of loading sessions may be required before significant strength adaptation occurs. To our knowledge, this is the first study to assess estimated bone strength in martial artists with brick breaking experience.

The primary hypothesis of this study was that there would be a greater percent side-to-side difference in estimated bone strength in the brick-breaking group compared to the control group. This hypothesis was not supported, although the side-to-side difference in SSI_p tended to be greater at the humeral shaft in the brick breaking group (7.7%) than controls (5.3%); however this 2.4% difference between groups was not statistically significant. This finding is not consistent with other studies of similar nature examining different unilateral upper-body sports (Haapasalo et al., 2000; Warden et al., 2009). Haapasalo et al. (2000) found 12 former national level tennis players to have a 23.8% larger side-to-side difference in SSI_p at the humeral shaft than their matched controls. Similarly, Warden et al. (2009) found 15 baseball throwers to have a 30.2% larger side-to-side difference in SSI_p at the humeral shaft than their matched controls. There are a number of possible explanations for our results being inconsistent with Haapasalo et al. (2000) and Warden et al. (2009). Both of these studies reported their participants to have a higher frequency of loading sessions, greater number of loading years in their sport and a younger starting age of participation in their sport compared to the brick breaking participants in the present study, as displayed in table 8.

Table 8 Study comparison table

	Present Study	Haapasalo et al. (2000)	Warden et al. (2009)
Loading frequency	2-49 total breaks	5.3 training sessions/week	2229 throws/month
Starting age (SD)	24.9 (8.2)	9.8 (3.0)	6.5 (not given)
Years of participation (SD)	6.2 (4.3)	19.6 (5.3)	13.3 (not given)

Even though the loading frequencies are displayed in different units and Haapasalo et al. (2000) represented this by number of training sessions per week rather than number of loading sessions; it is evident that the loading frequency is much lower for the brick breakers in the present study compared to participants in Haapasalo et al. (2000) and Warden et al. (2009). Although, Daly (2007) suggests that relatively few loading sessions are required, the present study reveals that a minimum number of loading sessions may be required for bone adaptations to occur.

In addition to the differences in loading frequencies, starting age is an important factor to highlight. In examining the starting ages of the participants in both Haapasalo et al. (2000) and Warden et al. (2009) it is evident that they began participation in their unilateral sport during childhood and were likely prepubescent. In the present study this was not the case given that the mean starting age of brick breaking participants was 24.9 years, early adulthood. In this case our findings are consistent with Nara-Ashiwaza, Liu, Higuchi, Tokuyama, Hayashi et al. (2002) who found no side-to-side difference in the arms of female tennis players who had started tennis participation after 30 years of age, with a minimum of 3 years experience and playing on average of 3.8 time per week. The importance of starting age is supported by Kontulainen, Sievanen, Kannus, Pasanen and Vuori (2002) finding female racquet athletes who started before menarche to have a 13.7% greater side-to-side difference in estimated torsional strength at the humeral shaft compared to those who started after menarche. This difference in starting age is important given that there is a wealth of evidence indicating that the opportune time to receive physiological bone adaptation from loading is during the growing years (Daly, 2007; Khan, McKay, Kannus, Bailey, Wark, Bennell, 2001; Haapasalo et al., 2000; Guadalupe-Grau et al., 2009). Adaptation can still occur during adulthood; however the physiological response is not as great (Warden & Fuchs, 2009). This indicates that the starting age of our participants was likely a factor in our lack of a significant difference between groups.

Years of participation in the particular sport was also greater in Haapasalo et al. (2000) and Warden et al. (2009) with the years of experience being more than double than that of the brick breaking participants in the present study. It is evident that with greater number of participation years and higher loading frequency that the participants in Haapasalo et al. (2000) and Warden et al. (2009) had much greater exposure the loading stimulus over the participants in the present study.

Although no significant difference was found between groups in the percent side-to-side difference, individual scores suggest that certain brick breaking participants may have had some adaptation over controls (participant 3, 4, 5, & 10). Individual scores are presented in Table 6. This evidence may suggest that a firm conclusion of lack of bone adaptations in the brick breaking activity may not entirely be justified, which is supported by findings of our secondary objective.

The secondary hypothesis was that the total number of brick breaks would be correlated with percent side-to-side difference in estimated bone strength. This hypothesis was confirmed with a positive correlation displaying that as the total number of brick breaks increased so did the percent side-to-side difference in SSI_p at the humeral shaft. This suggests that a minimum number of loading sessions may be required prior to bone adaptation and that of our 13 participants, with mixed experience of 2-49 breaks, the ones with the greater number of breaks displayed a larger side-to-side difference. Schwab and Klein (2008) support this finding by pointing out that frequent short sessions are beneficial in stimulating bone adaptation. Within brick breaking it is evident that these loading session are in no doubt short, with typically one impact load, and from this correlation it appears that brick breakers with higher number of breaks displayed more bone adaptation compared to those with less breaks.

The third hypothesis of the study was that the load experienced during a brick break would be considered a high impact force, exceeding the suggested magnitude of 4 x BW. When analyzing the elbow strike it is evident that the force experienced is considered high impact with forces ranging from 3.4 x BW to 5.8 x BW (mean: 4.5 x BW), supporting our hypothesis. However, in the case of the palm heel strike this hypothesis is not supported, with forces ranging from 1.7 x BW to 4.0 x BW (mean: 2.6 x BW). This difference in force between techniques, leads to an additional explanation for rejection of our primary hypothesis given that 5 of the 13 brick breaking participants reported palm heel as their technique of choice. However, given that sports of lower impact such as tennis have found bone adaptations to loading (Haapasalo et al., 2000), it maybe suggested that our lack of difference in SSI_p between groups should not be attributed to the magnitude of loading.

In addition to force magnitude, Guadalupe-Grau et al. (2009) points out that bone adaptations are also dependent on forces rapid in application. Our findings show forces as high as 4496 N and time to initial force peak as fast as 4.25 ms indicating these forces are rapid in application and high in magnitude, which should be sufficient in stimulating bone adaptation. Compared to other literature assessing upper body impact sports and bone adaptation our force values exceed the forces noted in gymnastics of 2471 N (Daly et al., 1999) and tennis of 330 N (Wu et al., 2001). This suggests that the force magnitude in brick breaking within martial arts should be sufficient for bone adaptation.

Our findings of peak force and impact duration are fairly consistent with the findings of Wilk et al. (1983) given slightly different parameters. The peak vertical force in the present study ranged from 2075 N to 4496 N (mean: 2960 N), whereas Wilk et al. (1983) the largest peak force observed was about 3600 N and the mean force was 1900 N. The reason for our force values being higher is likely due to different set up of the brick stack. Wilk et al. (1983) had less bricks in a stack and a strike that did not break all the bricks was considered an unsuccessful break. These unsuccessful breaks yielded higher forces than strikes that broke all of the bricks. In this case all breaks in the present study would have been considered unsuccessful, given that the most brick broken was 7 out of 8. The fact that Wilk et al. (1983) had less bricks in the stack resulting in all the bricks being broken more often, most likely led to lower force values. The time to initial peak force in the present study is consistent with that of Wilk et al. (1983). Our time to initial peak force ranged from 3.75 to 6.5 ms and Wilk et al. (1983) reported the rise in force to last 3 to 5 ms.

Although, the present study predominantly focused on the impact force, this is not the sole factor contributing to bone adaptations to loading. It is suggested that the force caused by muscular contractions have significant influence on changes in bone strength (Hasegawa et al., 2001; Kaji et al., 2005; Rantalainen, Heinonen, Komi, & Linnamo, 2008).

4.1 Muscle Contribution to Bone Strength

A muscular contraction results in an applied load to the bones connected to the contracting muscles, and the stronger the contraction the larger the resulting load on the bone. With this, it is evident that muscular strength is an influential factor on bone adaptation to loading (Hasegawa et al., 2001; Kaji et al., 2005; Rantalainen et al., 2008). For this reason we included a measure of grip strength, which resulted in the brick-breaking group having 6.9% stronger values in their dominant arm compared to their non-dominant arm and the control group only having a 3.7% difference. Although no significant difference between groups was found, this evidence indicates that the asymmetries found in muscular strength should be considered with our positive correlation results of total number of brick breaks and SSI_p. Furthermore, the contribution of the arm musculature during the brick break may be more present during a palm heel strike compared to an elbow strike given that elbow extension occurs with a palm heel strike indicating contraction of the triceps muscles.

It is well known that muscular strength is proportional to muscle size (Heinonen, McKay, Whittall, Forster & Khan, 2001). Therefore, literature has begun to examine the relationship between muscle cross sectional area (MCSA) and estimated bone strength, finding mixed results. Heinonen et al. (2001) found a positive correlation between MCSA and cortical area in the tibia of prepubertal females. However, Warden et al. (2009) did not find a significant side-to-side difference in upper arm MSCA (3.6%) when a significant side-to-side difference was found in SSI_p (41.7%) in baseball players. Also, Hasegawa et al. (2001) compared the ability of grip strength and MCSA to predict estimates of bone strength and found grip strength to be a stronger determinant of estimated bone strength. With these mixed results it is evident that further research is needed examining the relationship between MCSA and estimates of bone strength.

4.2 Bone Geometric Adaptation to Loading

The manner in which bone adapts to loading is not only by a change in material property (BMD) but also, or perhaps more so, in geometric arrangement including area, thickness, and moment of inertia (Kontulainen et al., 2007). The estimate of bone strength chosen for the present study was SSI_p, which is determined by both cortical area and cortical density. Although, no significant difference was found between groups in percent side-to-side difference in SSI_p, both groups displayed a significant difference between arms. From examining cortical area and cortical density it is evident that the difference between arms in both groups was due to cortical area. The side-to-side difference in cortical area was found to be 5.2% in the brick breakers and a 5.6% in the controls, whereas, cortical density only reported a 0.3% difference in brick breakers and a -1.0% difference in controls.

Although both area and density are important factors in estimating bone strength, if a significant difference was found between groups, evidence suggests that it may have been more so due to increases in cortical area in the dominant arm. Bass, Saxon, Daly, Turner, Robling et al. (2002) compared side-to-side differences and found 7-11% increases in cortical area in a group of pre-pubertal competitive female tennis players. Daly et al. (1999) also found significant gains of cortical area in pre-pubertal gymnasts. In both cases these the gains in cortical thickness were seen as periosteal apposition, giving greater resistance to torsional forces by creating bone with a larger diameter of the outer surface. Although both of these studies involved pre-pubertal athletes, the findings of Haapasalo et al. (2000) and Warden et al. (2009) are similar with adult athletes. Haapasalo et al. (2000) and Warden et al. (2009) both found significant differences in cortical area between unilateral athletes and controls but no difference was found in cortical density.

4.3 Strengths and Limitations

A couple aspects of this study, such as the comparison model and unique population, assisted in the strength of our findings. A major strength of this study is unilateral aspect of brick breaking allowing for a within subject comparison model, controlling for various extraneous factors such as genetics, nutrition, and hormones. Secondly, including a control group allowed for the addition of between group comparisons, allowing for comparison of martial artist brick breakers to a matched, physically active population. Without the control group, the conclusion would have indicated a significant side-to-side difference in brick breakers and would have not been able to validate if this difference is above and beyond that of normal physically active populations. Additional strength comes from a symmetry focus in martial art training (Tan, 2004). The event of brick breaking is only one aspect in martial arts. Often times, before a martial artist begins attempting to break bricks it is required that they reach a certain level in their training. With this they would have been exposed to symmetrical training up to this point. The reason this strengthens our study is that it provides stronger evidence that the asymmetrical differences found in this population may be attributed to the event of brick breaking. Another strength of this study is that it is the first to study in detail, with a large number of subjects, the loading forces experienced during this type of brick breaking and between two different breaking styles.

As with strengths there are also limitations to be considered. Although the number of participants in the present study is comparable to Haapasalo et al. (2000) and Warden et al. (2009), a larger sample population would have been beneficial given the wide range of experience level in our participants. Furthermore, it should be noted that the standard deviations for the percent side-to-side differences were quite large and in some cases larger than the actual reported value. Larger sample population and exclusion of less experienced brick breakers would have decreased the variance. A limitation of running a correlation is that it does not indicate a cause and effect response. In this case it simply indicated that as the total lifetime brick breaks increased so did the percent side-to-side difference in SSI_p. Another possible limitation could be that the researcher was not blinded during data collection given that the researcher performed all recruitment and data collection (except for one of the pQCT measurements). Additionally, given that all questionnaires in the present study were self-reported in nature, a certain level of error should be considered given the recall time frame and the amount of detail requested. Lastly, the external validity of this unilateral activity is quite small given that the majority of people may not be willing to experience similar loading magnitudes as brick breaking to gain benefits in bone adaptations.

4.4 Implications and Future Research

The information and insight derived from this study can have various implications for future research. Primarily this study brought in a unique population to the area of bone research, one that challenged the limits of bone's response to low frequency high impact loading. To our knowledge, no other study has examined such an activity with as high a loading impact and as low a loading frequency in a unilateral activity. The information gathered from this study will help narrow down more specific loading patterns for future research. Future research that would strengthen our findings would include a higher number of experienced brick breakers with more stringent inclusion criteria, excluding the less experienced brick breakers who may not have had sufficient exposure for bone adaptation.

Future research on this area should include further exploration in muscle properties, larger variety of unilateral activities, and intervention studies. Research with further examination of muscular properties in experienced brick breakers would lend additional knowledge to the responsible mechanisms for bone adaptation in this population. Research with further analysis of frequency in regards to time period between breaks would be beneficial to determine how long bone strength gains can be maintained between breaks. This would knowledge would be beneficial given that a low number of total breaks (2-49 total lifetime brick breaks) occurred over an average of 6.2 years, suggesting long rest periods between breaks. The addition of examining MCSA and muscle activation during the brick breaking strikes would lend insight as to the degree of influence muscle activation and muscle size has on estimated bone strength. Examining a larger range of unilateral activities would contribute to the more specific understanding of loading magnitude versus loading frequency on bone adaptations. To date, there are a vast number of cross sectional studies examining certain populations and few intervention studies examining cause and effect situation, controlling additional extraneous variables.

CHAPTER 5

SUMMARY AND CONCLUSION

5.1 Summary

Bone strength is an important determinant in bone health. Diminished bone strength can lead to osteoporosis, a condition that is characterized by deterioration of bone tissue and loss of bone mass, leading to increased fracture risk (“Osteoporosis Canada”, 2009). When considering quality of life, the mechanical competence of bone is of great importance given that fractures lead to debilitation. Bone has been shown to be an ever-changing tissue that can be strengthened by increased mechanical loading and weakened by decreased mechanical loading (Bailey & Brooke-Wavell, 2008; Guadalupe-Grau et al., 2009). Exercise has been well established as a common mechanical loading activity to maintain bone health (Schwab & Klein, 2008). Activities that are of high impact have been shown to have a better response in building bone strength than those of lower impact (Daly, 2007; Guadalupe-Grau et al., 2009). Although, it is becoming well known that impact activity is an effective method in building bone strength, many questions have yet to be answered in terms of optimal mechanisms. It is known that impact activities with rapid application, dynamic force, and high in magnitude are ideal (Bailey & Brooke-Wavell, 2008), however there is less evidence to support the effects of frequency (Daly, 2007; Vainionpaa et al., 2006) and the type of force to improve bone structure and geometry (Haapasalo et al., 2000). Many of the high impact activities previously studied are lower body type activities such jumping and running. Lower body impact activities are beneficial for improving bone health of the hip and leg. However, there is little research on the effect of upper body high impact activities on the strength of the forearm bones. Ideally, when assessing mechanical effects on bone, other known factors that impact bone strength such as hormones, nutrition and genetics need to be controlled. A model that provides internal control for these factors is a unilateral comparison of bone properties within a population of dominant limb activity (Bailey & Brooke-Wavell, 2008). A human population that encompasses all of the suggested ideal mechanisms in the upper body would be martial artists who participate in brick breaking. This population provides an ideal model to verify if side-to-side differences are present with higher impact and lower frequency activities. Therefore, the purpose of this study was to determine if the martial artist involved in brick breaking exhibit stronger estimated bone strength in their dominant arm compared to their non-dominant arm over controls.

5.2 Conclusion

Brick breaker's bone strength in the loaded arm seemed to have not adapted for high impact forces. However, the association between total number of breaks (impacts) and side-to-side strength difference suggests that a minimum number of loading sessions may be required before significant strength adaptation occurs. Although higher than other upper body impact sports, the impact from brick breaking was not of sufficient magnitude to be considered high impact by exceeding 4 x BW.

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Appendix A

Ethics: Certificates of Approval

UNIVERSITY OF SASKATCHEWAN

Biomedical Research Ethics Board (Bio-REB)

Certificate of Approval

PRINCIPAL INVESTIGATOR	DEPARTMENT	Bio #
Karen Chad	Kinesiology	09-59

INSTITUTION(S) WHERE RESEARCH WILL BE CARRIED OUT
Physical Activity Complex (PAC)
University of Saskatchewan
Saskatoon SK

STUDENT RESEARCHERS
Blair Healey

SPONSORING AGENCIES
IN APPLICATION

TITLE
: The Effect of Upper Body High Impact Exercise on Bone Mass and Structural Geometry

ORIGINAL REVIEW DATE	APPROVED ON	APPROVAL OF	EXPIRY DATE
20-Mar-2009	17-Apr-2009	Researcher's Summary Research Participant Information and Consent Form (17-Apr-2009) Recruitment Poster Health Control Recruitment Poster Martial Artist	19-Mar-2010

Delegated Review: ☒ Full Board Meeting: ☐

CERTIFICATION

The study is acceptable on scientific and ethical grounds. The Bio-REB considered the requirements of section 29 under the Health Information Protection Act (HIPA) and is satisfied that this study meets the privacy considerations outlined therein. The principal investigator has the responsibility for any other administrative or regulatory approvals that may pertain to this research study, and for ensuring that the authorized research is carried out according to governing law. This approval is valid for the specified period provided there is no change to the approved protocol or consent process.

FIRST TIME REVIEW AND CONTINUING APPROVAL

The University of Saskatchewan Biomedical Research Ethics Board reviews above minimal studies at a full-board (face-to-face) meeting. Any research classified as minimal risk is reviewed through the delegated (subcommittee) review process. The initial Certificate of Approval includes the approval period the REB has assigned to a study. The Status Report form must be submitted within one month prior to the assigned expiry date. The researcher shall indicate to the REB any specific requirements of the sponsoring organizations (e.g. requirement for full-board review and approval) for the continuing review process deemed necessary for that project. For more information visit http://www.usask.ca/research/ethics_review/.

REB ATTESTATION

In respect to clinical trials, the University of Saskatchewan Research Ethics Board complies with the membership requirements for Research Ethics Boards defined in Division 5 of the Food and Drug Regulations and carries out its functions in a manner consistent with Good Clinical Practices. This approval and the views of this REB have been documented in writing. The University of Saskatchewan Biomedical Research Ethics Board has been approved by the Minister of Health, Province of Saskatchewan, to serve as a Research Ethics Board (REB) for research projects involving human subjects under section 29 of The Health Information Protection Act (HIPA).

G McKay

Gordon McKay, Ph.D., Vice-Chair
University of Saskatchewan
Biomedical Research Ethics Board

Please send all correspondence to:

Research Ethics Office
University of Saskatchewan
Box 5000 RPO University
1607 – 110 Gymnasium Place
Saskatoon, SK Canada S7N 4J8

UNIVERSITY OF SASKATCHEWAN

Biomedical Research Ethics Board (Bio-REB)

Certificate of Approval

PRINCIPAL INVESTIGATOR
Joel Lanovaz

DEPARTMENT
Kinesiology

Bio #
09-117

INSTITUTION(S) WHERE RESEARCH WILL BE CARRIED OUT
Physical Activity Complex (PAC)
University of Saskatchewan
Saskatoon SK

SUB-INVESTIGATOR(S)
Karen Chad, Saija Kontulainen

STUDENT RESEARCHERS
Blair Healey, David Kobylak, Mike Smith

SPONSORING AGENCIES
UNIVERSITY OF SASKATCHEWAN - COLLEGE OF KINESIOLOGY

TITLE
: Arm Biomechanics and Impact Forces During Brick Breaking

ORIGINAL REVIEW DATE	APPROVED ON	APPROVAL OF	EXPIRY DATE
10-Jun-2009	02-Jul-2009	Researcher's Summary (05-Jun-2009) Research Participant Information and Consent Form (05-Jun-2009)	09-Jun-2010

Delegated Review: ☒ Full Board Meeting: ☐

CERTIFICATION
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G McKay

Gordon McKay, Ph.D., Vice-Chair
University of Saskatchewan
Biomedical Research Ethics Board

Please send all correspondence to:

Research Ethics Office
University of Saskatchewan
Box 5000 RPO University
1607 – 110 Gymnasium Place
Saskatoon, SK Canada S7N 4J8

Appendix B

Consent forms

Research Participant Information and Consent Form

TITLE: The Effect of Upper Body High Impact Exercise on Bone Mass and Structural Geometry

PROTOCOL / STUDY NUMBER:

PRINCIPAL INVESTIGATOR: Dr. Karen Chad
College of Kinesiology, University of Saskatchewan
87 Campus Drive, Saskatoon SK S7N 5B2 Canada
Telephone: (306) 966-1615
Fax: (306) 966-4737
Email: karen.chad@usask.ca

STUDENT INVESTIGATOR: Blair Healey

EMERGENCY PHONE NUMBER: 306-966-1123

INTRODUCTION
You are invited to take part in this research study because we would like to see how high impact training might affect the quality and shape of bones in order to see how different activities increase bone strength.

Your participation is entirely voluntary, so it is up to you to decide whether or not you wish to take part. If you decide not to take part, you do not have to provide a reason and it will not affect your relationship with any of the investigators, the College of Kinesiology, or the University of Saskatchewan. You will not lose the benefit of any medical care to which you are entitled or are presently receiving or affect employment or academic standing, as applicable. If you decide to take part in this study, you are still free to withdraw at any time during the investigation and without giving any reasons for your decision.

This consent form may contain words that you do not understand. Please ask the study the study staff to explain any words or information that you do not clearly understand. You may ask as many questions as you need to understand what the study involves. Please feel free to discuss this with your family, friends or family physician.

This will be a local study and Karen Chad and Blair Healey expect to enrol 50 participants from Saskatchewan and the surrounding area.

STUDY PURPOSE
Bone shape and strength is very important when it comes to bone health. The shape and strength of bone can be strengthened through different types of physical activity. In this project we hope to get a better understanding of the relationship between high impact activities and bone properties. The outcomes from this project will help us get a better understanding of how people might be able to protect their bone health through participating in physical activity. This study is an observational study, looking at differences in bone strength and shape between martial artists who participate in brick breaking events and those who are physically active but not involved in any brick breaking events.

STUDY DESIGN

A. There will be two groups of participants involved in this study. One group will be those who take part in regular brick breaking events as part of their sport and the other group will be non-brick-breaking participants.
B. The total time required from you will be 60 minutes.

STUDY PROCEDURES

A. You will be asked to come for one visit only and it should take no more than 60 minutes.
B. (i)The study procedure will involve both arms scanned by an instrument called peripheral quantitative computer tomography (pQCT), which obtains images in a slice view. Four areas of the arm will be scanned: a) the lower forearm close to the wrist b) the middle forearm c) the upper forearm close to the elbow and d) middle of the upper arm. This instrument is used to gather information regarding the shape and strength of bones. During this procedure you will be seated with your arm supported and extended out to the side through the pQCT. The pQCT is a large donut shaped structure with the inner circle being large enough for you arm to fit into. From this position the pQCT will slide along the length of your arm and stop at specific locations to take the scans.
(ii) Completing four questionnaires asking about age, lifelong history of physical activity, diets, brick breaking history, past arm fracture(s), and medical history regarding bone metabolism. You have the right to refuse to answer any questions they feel uncomfortable with.
(iii) Performing two grip strength assessments with each hand by squeezing a hand grip tool with full effort.

BENEFITS
If you choose to participate in this study, there may not be direct benefits to you. It is hoped the information gained from this study can be used in the future to benefit other people concerned with bone health. However, you will be provided with images of your scans which will provide you with information about your bone and muscle size and volumetric bone density. This information cannot be used for diagnostic purposes of osteoporosis or related fracture risk.

RISKS AND DISCOMFORTS

The minor risks of this study involve exposure to small amounts of radiation during the pQCT scan. The total amount of radiation to which you will be exposed is very low, an average of 22 mSV. This level of radiation is equivalent to what you would be exposed to by taking a return flight from Saskatoon to Toronto on a commercial airline. The typical exposure from a routine dental x-ray for example is 150mSV.

COST AND REIMBURSEMENTS

You will not be charged for the study, nor will be you paid for participating.

CONFIDENTIALITY AND LEGAL RIGHTS

The investigators will keep your personal information confidential. Your name will not be used at all in the study records. Instead, a special number (which may include your initials and date of birth but not your name or address) will be used. None of the your health records will be reviewed or copied.

Your study records, including your questionnaire and scan information, will be kept for 5 years in a locked cabinet in Dr. Chad's office at the College of Kinesiology. Your information and the results of the study will also be recorded in a computer database. Only the investigators will have access to your study records, and know your name. No other people or groups will have access to the data or your information. The results of this study will be presented in a scientific meeting and published in a scientific journal, but your identity will never be revealed.

By signing this document, you do not waive any of your legal rights.

NEW INFORMATION

The study investigator will tell you about any new information that may arise before or during the study that may affect your health, welfare, or willingness to stay in this study.

VOLUNTARY WITHDRAWAL FROM THE STUDY

If you do decide to take part in this study, you are still free to withdraw at any time and without giving reasons for your decision. There will be no penalty or loss of benefits to which you are otherwise entitled. If you choose to enter the study and then decide to withdraw at a later time, all data collected about you during enrolment in the study will be retained for analysis up to the point of your withdrawal.

AFTER COMPLETION OF THE STUDY

After your participation, you will be provided a summary of your bone and muscle size in comparison with the reference data (average values from the study and the scale from which the values are obtained). Results of the study objectives will be emailed to you if you want to receive this information.

CONTACT INFORMATION

If you have any questions about this study or your care/treatment or desire further information about this study before or during participation, you can contact Karen Chad by e-mail Karen.chad@usask.ca or by phone (306) 966-1615.

If you have any questions about your rights as a research subject or concerns about the study, you should contact the Chair of the Biomedical Research Ethics Board, c/o the Ethics Office, University of Saskatchewan, at 306-966-4053.

This study has been reviewed and approved on ethical grounds by the University of Saskatchewan Biomedical Research Ethics Board. The Research Ethics Board reviews human research studies. It protects the rights and welfare of the people taking part in those studies.

CONSENT TO PARTICIPATE

I have read (or someone has read to me) the information in this consent form. I understand the purpose and procedures, the possible risks and benefits of the study. I was given sufficient time to think about it. I had the opportunity to ask questions and have received satisfactory answers to all of my questions.

I am free to withdraw from this study at any time for any reason and the decision to stop taking part will not affect my future medical care relationship with the College of Kinesiology or the University of Saskatchewan. I agree to follow the study investigator's instructions and will tell the study investigator at once if I feel I have had any unexpected or unusual symptoms.

I voluntarily consent to take part in this research study and give permission to the use and disclosure of my de-identified questionnaires and bone scans collected for the research purposes described above.

By signing this document I do not waive any of my legal rights. I will be given a signed copy of this consent form.

_______________________________ _______________________________ _____/____/____
Printed Name of Participant Signature Day/Month/Year

_______________________________ _______________________________ _____/____/____
Name of person obtaining consent Signature Day/Month/Year

I consent to be contacted in the future about further participation:

Yes / No (please circle one)

For participants age 16 & 17:
Parent's Statement:

I understand the purpose and procedures of this study as described and I voluntarily agree to allow my child to participate. I understand that at any time during the study, he will be free to withdraw without jeopardizing any medical management, employment or educational opportunities. I understand the contents of the consent form, the proposed procedures and possible risks.

I have had the opportunity to ask questions and have received satisfactory answers to all inquiries regarding this study.

____
_____/____/____
Day/Month/Year

Parent or Guardian Signature

Research Participant Information and Consent Form

Title: Arm biomechanics and impact forces during brick breaking

Principal Researcher: **Dr. Joel Lanovaz**, Assistant Professor
College of Kinesiology
87 Campus Drive
Saskatoon, SK S7N 5B2
Ph: 306-966-1073
Email: joel.lanovaz@usask.ca

Other Researchers: Dr. Karen Chad (College of Kinesiology)
Dr. Saija Kontulainen (College of Kinesiology)

Student Researchers: Blair Healey (College of Kinesiology), David Kobylak (College of Kinesiology)
Mike Smith (College of Kinesiology)

Introduction:
You are invited to take part in this research study because we are interested in measuring the impact forces, arm movements and loading patterns during martial arts brick breaking. This will help us in our investigation of how loading can affect bone growth.

Your participation is entirely voluntary, so it is up to you to decide whether or not you wish to take part. If you decide not to take part, you do not have to provide a reason and it will not affect your relationship with any of the researchers. If you are a student, your academic standing will not be affected in any way. If you decide to take part in this study, you are still free to withdraw at any time without any consequences or giving any reasons for your decision.

This consent form may contain words that you do not understand. Please ask any of the researchers listed above to explain any words or information that you do not clearly understand. You may ask as many questions as you need to understand what the study involves. Please feel free to discuss this with your family, friends or family physician.

Note that neither the institution nor any of the investigators or staff will receive any direct financial benefit from conducting this study.

The study will be conducted and the Musculoskeletal Biomechanics Lab (MBL) located in room 355 of the Physical Activity Complex on the University of Saskatchewan campus.

Study Purpose:
Impact forces and arm movements associated with martial arts brick breaking have only been scientifically measured a few times. This makes it hard to compare the loading conditions seen in brick breaking with the loading conditions seen in other activities involving impacts such as tennis. Finding out more detailed information about the forces involved in brick breaking will

help us in other studies where we are interested in the relationship between high impact activities and bone health.

Study Design:

This study will examine the forces and arm movements of male participants attempting to break a stack of bricks. You can be involved in this study if you are 18 years of age or older and free of any muscle or bone disease. To participate, you must be an experienced martial artist with a minimum rank of black-belt. You must also have a minimum of one year of brick breaking competition experience and be actively involved in brick breaking events within the past 12 months.

Study Procedures:

If you choose to participate, you will be asked to come to the Musculoskeletal Biomechanics Lab (MBL) located in room 355 of the Physical Activity Complex on the University of Saskatchewan campus for one visit. The visit should take about 1 hour to complete.

During the visit, you will be asked to make one attempt to break as many bricks as possible in a stack of eight (8) bricks. The bricks will be separated by standard quarter-inch hex nuts placed at the corners and the entire stack will be supported on two cinder blocks.

For your attempt, data will be gathered using a motion capture system that tracks the movements of your limbs. The system has specialized cameras that track small reflective markers that will be attached to your arms using hypoallergenic two-sided tape. At the same time, we will record forces that you apply to the bricks using an instrumented platform embedded in the floor. Also a high speed video camera will be used to record your movements as reference data during analysis. A small device called an accelerometer will also be taped to your arm. The accelerometer records the impact accelerations of your arm during the attempt. Finally, we will also use an electromyography (EMG) system to gather information about the activation patterns of your arm muscles. The EMG system uses small sensors taped to your skin to passively record the natural electrical activity produced by your muscles. The areas where the electrodes will be placed may need to be shaved.

You may cancel your attempt or withdraw from the study at any time and for any reason.

Benefits:

If you choose to participate in this study, you will not experience any direct benefits. It is hoped that the information gained from this study can benefit other people looking at the biomechanics of martial arts and other people concerned with bone health.

Risks and Discomforts:

The risk of injury while participating in this study is the same as you would experience for any other brick breaking activity. Possible direct side effects of brick breaking attempts include (but are not limited to) soreness, swelling, bruising, cuts, abrasions and broken bones.

It is possible that during the testing you may feel some discomfort on your skin or even an allergic reaction from the adhesive tape that temporarily sticks the tracking markers and the EMG sensors to your skin, but this is rare.

There may be unexpected and unknown risks during the study, or after the study has been completed.

Research Subject Responsibilities:
The responsibility of the subject is to come to the study on the decided time, perform the tasks, follow directions.

Cost And Reimbursements:
There will be no cost to you for participation in this study and the researchers will provide no reimbursements.

Research-Related Injury:
In the case of an injury related to the study, you should seek immediate care and, as soon as possible, notify the study's principal investigator. Necessary medical treatment will be made available at no cost to you. By signing this document, you do not waive any of your legal rights. Neither the research ethics committee nor the researchers can speak on behalf of Saskatchewan Health on what (or may not) be covered in the event of a research related injury.

Confidentiality:
While complete subject anonymity cannot be guaranteed, every effort will be made to ensure that the information you provide for this study is kept entirely confidential. Your name will not be attached to any information, nor mentioned in any study report, nor be made available to anyone except the research team. It is the intention of the research team to publish results of this research in scientific journals and to present the findings at related conferences and workshops.

Most research findings will be reported in aggregate form without reference to specific participants. In the event individual data are used, only participant codes will be referenced and your identity will not be revealed. Some digital still images and video are taken during data collection for reference. These images are kept confidential. If an image is used for publication purposes, it will be altered to remove all information that could be used to identify a specific individual.

Data are stored on a password protected digital media (i.e., DVD) in a locked lab/office in the College of Kinesiology to which only the researchers will have access. The data will be used for dissertation and publication purposes only, and will be retained for a minimum of five years. Normally data is retained for a period of five years post-publication, after which time it may be destroyed.

New Information:
The research team will tell you about new information that may affect your health, or

willingness to stay in this study when it arises.

Voluntary Withdrawal From The Study:
If you do decide to take part in this study, you are still free to withdraw at any time and without giving reasons for your decision. There will be no penalty or loss of benefits to which you are otherwise entitled. If you choose to enter the study and then decide to withdraw at a later time, any data collected up to that point will be retained. However, no further data will be collected, and the data already collected will not be used, but will be held and destroyed after five years.

Withdrawal Initiated By The Investigator Or Sponsor:
You may be withdrawn from the study if:

-Staying in the study would be harmful.
-You need treatment not allowed in the study.
-You fail to follow instructions.
-The study is cancelled by the sponsor for administrative or other reasons.

After Completion Of The Study:
Once the study is completed the results of the study will be made available to you. A lay summary of the aggregate results will be available to you on request after December 31st, 2009 and can be obtained by contacting Dr. Lanovaz.

Contact Information:
If you have any questions or concerns about this study or desire further information about this study before or after participation, you can contact Dr. Joel Lanovaz at 306-966-1073.

If you have any questions about your rights as a research subject or concerns about the study, you should contact the Ethics Office, University of Saskatchewan, at 306-966-4053 or the Office of Research Services, University of Saskatchewan, at 306-966-2084.

This study has been reviewed and approved on ethical grounds by the University of Saskatchewan Biomedical Research Ethics Board. The Research Ethics Board reviews human research studies. It protects the rights and welfare of the people taking part in those studies.

Consent To Participate:
I have read (or someone else has read to me) the information in this consent form. I understand the purpose and procedures, the possible risks and benefits of the study. I was given sufficient time to think about it, and to ask questions, receiving satisfactory answers to all of my questions.

I am free to withdraw from this study at any time for any reason and the decision will not affect your relationship with the researchers.

I voluntarily consent to take part in this research study and give permission to the use and disclosure of my de-identified personal health information collected for the research purposes described above.

By signing this document I do not waive any of my legal rights. I will be given a signed copy of this consent form.

____

Printed Name of Participant:

____________________________________ ______________

Signature of Participant Date

____

Printed Name of person obtaining consent

____________________________________ ______________

Signature of person obtaining consent Date

Appendix C

Medication and Bone Health Questionnaire

Subject ID: _______

Date: ________________ (dd/mm/yy)   Date of Birth: _______________ (dd/mm/yy)

Medication and Bone Health Questionnaire

Please answer the following questions to the best of your ability and you do not need to answer any question you do not feel comfortable to answer. These questions are asked for inclusion/exclusion criteria only.

1. Are you taking any prescription medications?
Remember to include prescribed medications
Yes □
No □
Not Sure □

If yes, how many prescription medications are you taking?

____

Name: ___________ **Name:** ___________ **Name:** ___________
Dosage: ___________ **Dosage:** __________ **Dosage:** __________

2. Are you on any special diets?
Yes □
No □
Not Sure □

If yes, describe?

____

____

3. Are you taking any mineral supplements?

Remember to include below
Yes □
No □
Not Sure □

If yes, how many mineral supplements are you taking?

____

Name: ___________	**Name: ___________**	**Name: ___________**
Dosage: ___________	**Dosage: __________**	**Dosage: __________**

4. Are you taking any over-the-counter medications?
Pain killers, antacids, allergy pills and hydrocortisone creams are all examples of over-the-counter medications.
Yes □
No □
Not Sure □

If yes, how many over-the-counter medications are you taking?

Name: ___________	**Name: ___________**	**Name: ___________**
Dosage: ___________	**Dosage: __________**	**Dosage: __________**

5. Have you ever had a wrist or arm fracture?

Yes □
No □
Not Sure □

If yes, please indicate the body site and date:

Left or Right (circle)   Date: (mm/yy) _____/______

6. Have you ever had any other broken bone or stress fracture?

Yes □
No □
Not Sure □

If yes, please indicate the bone and date:

Bone _________________________

Left or Right (circle)   Date: (mm/yy) _____/______

7. Have you ever been treated for or diagnosed with arthritis or other joint or bone disease?

Yes □
No □
Not Sure □

If yes, please explain____

____

_____

Appendix D

Total Lifetime Physical Activity Questionnaire

Occupational Activity Subject ID:__________

To the best of your ability, please list what jobs (paid or volunteer) that you have done **at least 8 hours a week for four months of the year** over your lifetime. Start with your first job and end with the most recent or current job. (Use back of page if needed)

No.	Description of Occupation Activity	Age Started	Age Ended	No. of Months/ Year	No. of Days/ Week	Time/Day		Intensity of Activity (1, 2, 3, 4)*
						Hours	Min.	
1								
2								
3								
4								
5								
6								
7								
8								

9								

* Intensity if occupational activity defined as:
1 = jobs that require only sitting with marginal walking
2 = jobs that require a minimal amount of physical effort such as standing and slow walking with no increase in heart rate and no perspiration.
3 = jobs that require carrying light loads (5-10 lb), continuous walking mainly indoor activity and that would increase the heart rate slightly and cause light perspiration.
4 = jobs that require carrying heavy loads (>10 lb), brisk walking, climbing, mainly outdoor activity, that increases heart rate substantially and causes heavy sweating.

<u>Household Activities</u>

Please include only those activities that you have done at **least 7 hours per week for 4 months of the year**. It may help you to consider what a typical day is for you. Then think about how many hours of household and gardening or yard work you do in a typical day. For seasonal activities, such as gardening, you can report those separately from all other household activities that are done all year.

No.	Description of Household Activity	Age Started	Age Ended	No. of Months/ Year	No. of Days/ Week	Time/Day		Hours per day spent in activities that were in category: *		
						Hours	Min.	2	3	4
1										
2										
3										
4										
5										

6										
7										
8										

* Intensity of household activity defined as:
1 = activities that can be done sitting
2 = activities that require minimal effort such as those done standing, sitting or with slow walking, that do not require much physical effort.
3 = activities that are not exhausting, that increase the heart rate slightly and that may cause some light perspiration.
4 = activities that increase the heart rate and cause heavy sweating such as those requiring lifting, moving heavy objects, rubbing vigorously for fairly long periods.

Exercise/Sport Activities

Please report the activities that you have done at least **2 hours per week for at least 4 months of the year**. Please tell us what exercise and sports activities you have done **at least 10 times** during your lifetime. Besides sports and exercise, we are also interested in knowing whether you walked or biked to work. If you have done this, please report all the information as for the other sports activities. (Use back if needed)

No.	Description of Exercise/Sport Activity	Age Started	Age Ended	Frequency of activity				Time/Day		Intensity of Activity (1, 2, 3, 4)*
				Day	Week	Month	Yr	Hours	Min.	
1										
2										
3										
4										

5										
6										
7										
8										

* Intensity of household activity defined as:

1 = activities that can be done sitting

2 = activities that require minimal effort such as those done standing, sitting or with slow walking, that do not require much physical effort.

3 = activities that are not exhausting, that increase the heart rate slightly and that may cause some light perspiration.

4 = activities that increase heart rate and cause heavy sweating

Appendix E

Waterloo Handedness Questionnaire

Appendix 2 – Waterloo Handedness Questionnaire

INSTRUCTIONS: Please indicate your hand preference for the following activities by circling the appropriate response. Think about each question. You might try to imagine yourself performing the task in question. Please take your time.

- If you use one hand 95% of the time to perform the described activity, then circle right always or left always as your response.
- If you use one hand about 75% of the time, then circle right usually or left usually.
- If you use both hands roughly the same amount of time, then circle equally.

1. Which hand do you use for writing?
Left Always Left Usually Equally Right Usually Right Always

2. With which hand would you unscrew a tight jar lid?
Left Always Left Usually Equally Right Usually Right Always

3. In which hand do you hold a toothbrush?
Left Always Left Usually Equally Right Usually Right Always

4. In which hand would you hold a match to strike it?
Left Always Left Usually Equally Right Usually Right Always

5. Which hand would you use to throw a baseball?
Left Always Left Usually Equally Right Usually Right Always

6. Which hand do you consider the strongest?
Left Always Left Usually Equally Right Usually Right Always

7. With which hand would you use a knife to cut bread?
Left Always Left Usually Equally Right Usually Right Always

8. With which hand do you hold a comb when combing your hair?
Left Always Left Usually Equally Right Usually Right Always

9. Which hand do you use to manipulate implements such as tools?
Left Always Left Usually Equally Right Usually Right Always

10. Which hand is the most adept to picking up small objects?
Left Always Left Usually Equally Right Usually Right Always

Appendix G

Brick Breaking History Questionnaire

Brick Breaking History

Subject ID:______________

1. Please describe your brick breaking activity with your **dominant** arm during your time as a martial artist (Include unsuccessful attempts).

Date:	Number Broken / Number of bricks in stack, Technique:
Example: July 4, 2009	**5/8, Elbow**

2. Please describe your brick breaking activity with your **non-dominant** arm during your time as a martial artist (Include unsuccessful attempts).

Date:	Number Broken / Number of bricks in stack, Technique:
Example: July 4, 2009	**5/8, Palm Heel**

3. What do you do to prepare yourself for brick breaking (i.e. How do you train)?

4. What martial art(s) do you train in?

5. What are you belt ranks in those martial arts?

6. Which kind of brick are you most familiar with breaking? (Circle)

Appendix G

Statistical Tables

Between group independent t-test: age, height, weight, and Waterloo score

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Age	Equal variances assumed	.064	.803	-.147	24	.885	-.61538	4.19587	-9.27524	8.04447
	Equal variances not assumed			-.147	23.980	.885	-.61538	4.19587	-9.27561	8.04484
Height	Equal variances assumed	.220	.643	-1.132	24	.269	-2.34615	2.07235	-6.62326	1.93096
	Equal variances not assumed			-1.132	22.680	.269	-2.34615	2.07235	-6.63648	1.94417
Weight	Equal variances assumed	.157	.696	-.004	24	.997	-.03846	8.98905	-18.59095	18.51403
	Equal variances not assumed			-.004	23.956	.997	-.03846	8.98905	-18.59274	18.51582
Handedness	Equal variances assumed	.004	.952	-.034	24	.973	-.077	2.245	-4.711	4.557
	Equal variances not assumed			-.034	20.951	.973	-.077	2.245	-4.747	4.593

Within group dependent t-test: Brick Breakers side-to-side grip strength

Paired Samples Test[a]

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	DomGrip - NDomGrip	3.69231	4.25019	1.17879	1.12394	6.26067	3.132	12	.009

Within group dependent t-test: Controls side-to-side grip strength

Paired Samples Test[a]

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	DomGrip - NDomGrip	2.03846	5.32471	1.47681	-1.17923	5.25615	1.380	12	.193

a. Group = BBC

Between group independent t-test: Humeral length comparison

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
DomHummerus	Equal variances assumed	.002	.969	.237	24	.815	1.5769	6.6638	-12.1765	15.3303
	Equal variances not assumed			.237	23.081	.815	1.5769	6.6638	-12.2055	15.3593
NDomHummerus	Equal variances assumed	.744	.397	.405	24	.689	2.2692	5.6052	-9.2993	13.8377
	Equal variances not assumed			.405	23.034	.689	2.2692	5.6052	-9.3250	13.8635

Within group dependent t-test: Brick Breakers side-to-side comparison of bone measures

Paired Samples Test[a]

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	SSIpNonDom - SSIpDom	-123.95385	86.37765	23.95685	-176.15134	-71.75636	-5.174	12	.000
Pair 2	CoDNonDom - CoDDom	-1.06154	57.28968	15.88930	-35.68135	33.55827	-.067	12	.948
Pair 3	CoANonDom - CoADom	-16.02462	16.47053	4.56810	-25.97766	-6.07158	-3.508	12	.004

a. Group = BB

Within group dependent t-test: Controls side-to-side comparison of bone measures

Paired Samples Test[a]

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	SSIpNonDom - SSIpDom	-95.53077	132.49734	36.74815	-175.59811	-15.46343	-2.600	12	.023
Pair 2	CoDNonDom - CoDDom	10.73077	29.54292	8.19373	-7.12184	28.58338	1.310	12	.215
Pair 3	CoANonDom - CoADom	-17.16923	16.71169	4.63499	-27.26800	-7.07046	-3.704	12	.003

a. Group = Controls

Between group independent t-test: Percent side-to-side comparison between groups

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
SSIpPercDiff	Equal variances assumed	.661	.424	.988	24	.333	2.43077	2.46074	-2.64795	7.50949
	Equal variances not assumed			.988	23.183	.333	2.43077	2.46074	-2.65744	7.51898
CoDPercDiff	Equal variances assumed	3.795	.063	.742	24	.466	1.30769	1.76334	-2.33166	4.94704
	Equal variances not assumed			.742	17.786	.468	1.30769	1.76334	-2.40014	5.01552
CoAPercDiff	Equal variances assumed	.015	.903	-.220	24	.828	-.44615	2.03168	-4.63933	3.74703
	Equal variances not assumed			-.220	23.949	.828	-.44615	2.03168	-4.63980	3.74750

Correlation: SSI_p and Total number of brick breaks

Correlations

		HumeralShaft	TotalBreak
HumeralShaft	Pearson Correlation	1	.727**
	Sig. (1-tailed)		.002
	N	13	13
TotalBreak	Pearson Correlation	.727**	1
	Sig. (1-tailed)	.002	
	N	13	13

**. Correlation is significant at the 0.01 level (1-tailed).