FLUCTUATING ASYMMETRY IN THE PROTOHISTORIC ARIKARA

Natascha Storms
B.A., California State University, Sacramento, 2000

THESIS

Submitted in partial satisfaction of the requirements for the degree of

MASTER OF ARTS

in

ANTHROPOLOGY

at

CALIFORNIA STATE UNIVERSITY, SACRAMENTO

FALL
2009
FLUCTUATING ASYMMETRY IN THE PROTOHISTORIC ARIKARA

A Thesis

by

Natascha Storms

Approved by:

____________________________, Committee Chair
Dr. Samantha Hens

____________________________, Second Reader
Dr. M. Elizabeth Strasser

____________________________, Department Chair
Dr. Raghuraman Trichur

____________________________
Date
Student: Natascha Storms

I certify that this student has met the requirements for format contained in the University format manual, and that this thesis is suitable for shelving in the Library and credit is to be awarded for the thesis.

__________________________, Graduate Coordinator

Dr. Michael Delacorte Date

Department of Anthropology
Abstract

of

FLUCTUATING ASYMMETRY IN THE PROTOHISTORIC ARIKARA

by

Natascha Storms

Bioarchaeologists have used fluctuating asymmetry to compare the levels of environmental stress a skeletal population may have encountered during life. Fluctuating asymmetry is traditionally scored on the dentition, though recent studies have also examined the skull and epiphyseal union. Previous bioarchaeological health studies of the Arikara of North Dakota detected significant differences in the levels of environmental stress in pre-contact, contact and post-contact Arikaran populations. This thesis examines three Arikaran archaeological sites, Mobridge, Larson and Leavenworth, in an effort to test the sensitivity of epiphyseal union to environmental stress, measured by fluctuating asymmetry. The data were collected from the Overland skeletal collection housed by the University of Tennessee, Knoxville’s Department of Anthropology.

This thesis found that fluctuating asymmetry of epiphyseal union did not reveal any statistically significant differences among the people of the Mobridge, Larson or Leavenworth archaeological sites. These results suggest that epiphyseal union may not be an indicator of environmental stress during development or that the Arikara may exhibit high levels of canalization.

_______________________, Committee Chair
Dr. Samantha Hens

_______________________
Date
DEDICATION

I would like to dedicate this thesis to my family, who have supported and encouraged me no matter my direction. Also, to the Anthropology Department at California State University, Sacramento. Most especially my advisor, Dr. Samantha M. Hens, who encouraged my interests, answered my questions, gave me a direction when I was lost, and always sets high standards for all her students.
ACKNOWLEDGMENTS

I would like to acknowledge the University of Tennessee’s Department of Anthropology for graciously allowing me access to their Arikaran collection. More specifically, I extend my thanks to Dr. Lee Meadows Jantz for her assistance in the skeletal lab, as well as Dr. Kanya Godde, a former California State University, Sacramento graduate student. Kanya’s help with direction and transportation, and housing at the University of Tennessee, Knoxville was invaluable. I would also like to thank my advisor Dr. Samantha M. Hens, Dr. Martin Biskowski, my statistics professor, and Dr. M. Elizabeth Strasser.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dedication</td>
<td>.............................................................................................................</td>
<td>vi</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>.............................................................................................................</td>
<td>vii</td>
</tr>
<tr>
<td>List of Tables</td>
<td>.............................................................................................................</td>
<td>x</td>
</tr>
<tr>
<td>List of Figures</td>
<td>.............................................................................................................</td>
<td>xi</td>
</tr>
<tr>
<td>1.</td>
<td>INTRODUCTION ..............................................................................................................................</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Statement of Purpose ....................................................................................................................</td>
<td>4</td>
</tr>
<tr>
<td>2.</td>
<td>LITERATURE REVIEW: ASYMMETRY ..........................................................................................</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Directional Asymmetry .................................................................................................................</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Fluctuating Asymmetry ....................................................................................................................</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Asymmetry: Environmental or Genetic ........................................................................................</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Fluctuating Asymmetry: Environmental Stress ........................................................................</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>Fluctuating Asymmetry: Behavior .................................................................................................</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>Fluctuating Asymmetry: Conclusion .............................................................................................</td>
<td>33</td>
</tr>
<tr>
<td>3.</td>
<td>LITERATURE REVIEW: ARIKARA .........................................................................................</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Geographic and Temporal Designations for the Arikara .......................................................</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Site Descriptions .........................................................................................................................</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td>Mobridge .................................................................................................................................</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td>Larson .................................................................................................................................</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>Leavenworth .......................................................................................................................</td>
<td>44</td>
</tr>
<tr>
<td></td>
<td>Comparative Health Studies ...............................................................................................</td>
<td>46</td>
</tr>
<tr>
<td>4.</td>
<td>PROJECT SPECIFICATIONS ........................................................................................................</td>
<td>49</td>
</tr>
</tbody>
</table>
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Table Number</th>
<th>Table Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Longbone Growth - Site Comparison</td>
<td>47</td>
</tr>
<tr>
<td>2.</td>
<td>Perinatal Health - Site Comparison</td>
<td>48</td>
</tr>
<tr>
<td>3.</td>
<td>Epiphyseal Fusion Scores</td>
<td>56</td>
</tr>
<tr>
<td>4.</td>
<td>Location of Asymmetric Epiphyses</td>
<td>60</td>
</tr>
<tr>
<td>5.</td>
<td>Results of Paired Sample T-Test</td>
<td>62</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Arikara sample size</td>
<td>52</td>
</tr>
<tr>
<td>2.</td>
<td>Sex - Larson, Leavenworth, and Mobridge</td>
<td>53</td>
</tr>
<tr>
<td>3.</td>
<td>Age - Larson, Leavenworth, and Mobridge</td>
<td>54</td>
</tr>
<tr>
<td>4.</td>
<td>Age of individuals with unknown sex</td>
<td>55</td>
</tr>
<tr>
<td>5.</td>
<td>Asymmetric individuals by site</td>
<td>58</td>
</tr>
<tr>
<td>6.</td>
<td>Sex of asymmetric individuals</td>
<td>59</td>
</tr>
<tr>
<td>7.</td>
<td>Age of asymmetric individuals</td>
<td>60</td>
</tr>
<tr>
<td>8.</td>
<td>Number of asymmetries per individual</td>
<td>61</td>
</tr>
<tr>
<td>9.</td>
<td>Direction of asymmetries</td>
<td>62</td>
</tr>
<tr>
<td>10.</td>
<td>Albert and Green’s (1999) percent of asymmetrical Nubians</td>
<td>64</td>
</tr>
<tr>
<td>11.</td>
<td>Percentage of asymmetrical New World Arikarans</td>
<td>65</td>
</tr>
</tbody>
</table>
Chapter 1

INTRODUCTION

Biological anthropology endeavors to understand the dynamic interactions between individuals and their environment (Larsen, 2006). Specifically, it examines the effects of culture and environment on the human body (Armelagos and Van Gerven, 2003). Bioarchaeology, as a subfield, studies these interactions as reflected in the skeletons of past peoples (Larsen, 2006). While skeletons cannot provide the same level of information as a living informant, human remains continue to provide information concerning human lives and lifestyles (Armelagos and Van Gerven, 2003). Continuing developments in technology and methodology have provided additional avenues for bioarchaeological exploration and for understanding our past (Armelagos and Van Gerven, 2003; Larsen, 2006).

Bioarchaeological inquiry is focused around three main topics: behavior and lifestyle, quality of life, and biological relatedness (Larsen, 2006). Unequal measurements or asymmetry of the human skeleton have been interpreted in ways that addresses each of those topics (Al-Oumaoui et al., 2004; DeLeon, 2007; Harris and Nweesia, 1980; Hershkovitz et al., 1993; Little et al., 2002; Ruff and Jones, 1981; Žilvanović, 1983). Research has identified two main types of asymmetry, directional asymmetry and fluctuating asymmetry (DeLeon, 2007; Little et al., 2002; Mays et al., 1999; Mooney et al., 1985; Plochocki, 2002; Van Valen, 1962; Waddington, 1942, 1953).

Directional asymmetry, defined as asymmetry that affects one side of the body more than the other side, has been utilized as an indicator of habitual physical activity (Al-Oumaoui et al., 2004; Churchill and Formicola, 1997; Van Valen, 1962; Waddington, 1942, 1953). In repetitive activities, especially ones that require strength, bones respond by building extra bone tissue for additional muscle attachment. The specific muscle being used will influence the position of the marker (Dutour, 1986). Since humans are lateralized, or have preferential limb use, these
additional bony marks tend to occur on the dominant side (Blackburn and Knüsel, 2006; Bradshaw, 1991; Plato et al., 1980; Plochocki, 2004; Ruff and Jones, 1981). Knowing the habitual physical movements of an individual or group adds to bioarchaeological understanding of the behavior and lifestyle of a population (Al-Oumaoui et al., 2004; Churchill and Formicola, 1997; Dutour, 1986; Ledger et al., 2000; Mays, 1999). Bioarchaeologists use directional asymmetry to draw conclusions concerning behavior, workload, lifestyle, type of occupation, level of mobility and activity (Al-Oumaoui et al., 2004; Churchill and Formicola, 1997; Dutour, 1986; Ledger et al., 2000; Mays, 1999; Mays et al., 1999).

The evaluation of the quality of life of past populations utilizing asymmetry data includes implications concerning health, as well as diet (Kohn and Bennett, 1986; Little et al., 2002; Kieser et al., 1997; Mooney et al., 1985; Schell, 1981). Fluctuating asymmetry, defined as asymmetry favoring neither side of the body or the random difference between measures of a bilateral trait, is theoretically caused by random environmental effects mediated by developmental constraints (Debat and David, 2001; Van Valen, 1962; Waddington, 1942). The greater the environmental stress, whether it is disease, starvation, or fear for one’s life, the lower the quality of life an individual enjoyed.

Fluctuating asymmetry represents disruptions in the development of individuals caused by environmental stress (Kohn and Bennett, 1986; Little et al., 2002; Kieser et al., 1997; Mooney et al., 1985; Schell, 1981). Previous studies have shown the usefulness of fluctuating asymmetry as an indicator of the level of environmental stress encountered by individuals during their growth and development (Albert and Green, 1999; DeLeon, 2007; Harris and Nweeia, 1980; Kieser et al., 1997; Little et al., 2002). Studies show that with an increase in environmental stress during development, an increase in FA can be observed (Kieser et al., 1997; Kohn and Bennett, 1986; Mooney et al., 1985). When researchers compare levels of fluctuating asymmetry within and
between populations, their health and quality of life can be put into context, adding to our understanding of the past.

There is discussion concerning the heritability of skeletal asymmetry (Guatelli-Steinberg et al., 2006; Hall 2005; Houle 2000; Kieser et al., 1986; Möller, 1999; Swaddle, 1997; Van Dogen and Lens, 2000; Van Valen, 1962; Waddington, 1942, 1953). These studies question whether FA is a trait that can be inherited. Research questions cover a range of topics concerning FA and its possible connection to human genetics. Is the tendency to fluctuate a heritable trait (Möller and Thornhill, 1997a)? Is FA part of natural variation or the result of varying sensitivity to environmental stress (Albert and Green, 1999; Benderlioglu and Nelson, 2004; Little et al., 2002; Pomiankowski, 1997)? Is there a threshold level to the amount of stress a body can endure before FA results (Waddington, 1942; 1953)? Is there a genetic trait that lowers an individual’s sensitivity to environmental stress, which results in fluctuating asymmetry (Möller and Thornhill, 1997b)? Is that trait linked with the body’s ability to return to its previous developmental trajectory, also known as canalization (Hallgrimsson at al., 2002)? Studies examining the heritability of asymmetry lead to questions concerning the evolutionary pressures that created the ability for a trait to canalize its development after an environmental disruption, as well as discussions of genetic fitness (Guatelli-Steinberg et al., 2006; Hall 2005; Houle 2000; Kieser et al., 1986; Möller, 1999; Van Dogen and Lens, 2000; Van Valen, 1962; Waddington, 1942, 1953). Why does asymmetry occur and how did the ability to counteract asymmetry and return to a normal developmental course evolve? These are some of the questions researchers study concerning the heritability of fluctuating asymmetry.
Statement of Purpose

This study tests whether asymmetry of the union of the epiphyses to the diaphysis between the left and right sides during adolescent growth and development is an indicator of environmental stress. Utilizing data from three comparative cemetery populations, this study proposes research similar to the study done by Albert and Green (1999). Albert and Green analyzed two historically and genetically related populations, in which one site with historically documented environmental stress demonstrated a significant increase in fluctuating asymmetry of bilateral epiphyseal unions. This investigation will attempt to discover if the more environmentally stressed Arikaran population displayed higher degrees of fluctuating asymmetry.

The introduction of Europeans on the North American continent had many effects on the indigenous peoples such as the Arikara of the upper Missouri. Some of these effects were positive, like the introduction of the horse, which enabled greater mobility and food gathering (Rogers, 1990). Other effects, such as the spread of deadly and highly communicable diseases, such as smallpox, were not positive (Abel, 1939; Trimble, 1994). The Arikara were visited by several historical Euroamericans, such as Louis and Clark, who subsequently wrote about their experiences with the tribe. These observations establish historical documentation of the changing health status of the tribe. In addition, the Arikaran tribes left several archaeological sites ranging from before European contact, to post-contact periods, which previous researchers have evaluated for evidence of health status and environmental stress (Jantz and Owsley, 1984).

In 1984, Jantz and Owsley studied long bone growth of Arikara adolescents over three time periods. Through their study they were able to make some observations on the accuracy of ethno-historical documentation of environmental/nutritional stress incurred between the differing time periods. Their study demonstrated the environmental sensitivity of long bone growth (Jantz and Owsley, 1984).
Using the same skeletal samples of Arikara housed at the University of Tennessee, Knoxville, this study examines bilateral epiphyseal unions from three Arikaran archaeology sites, and documents three time periods. The study will test the environmental sensitivity of epiphyseal union, measured by bilateral asymmetry. The results will add to bioarchaeologies’ interpretation of population and individual health, social status and genetic robusticity.
Chapter 2

LITERATURE REVIEW: ASYMMETRY

Current literature is replete with studies concerning the biological meaning and social implications of asymmetries found in the human skeletal system (Churchill and Formicola, 1997; DeLeon, 2007; Houle, 2000; Hummert and Van Gerven, 1983; Kieser at al., 1997; Little et al., 2002; Naugler and Ludman 1996). These asymmetries range from timings of epiphyseal closure (Albert and Gren, 1999; Livshits et al., 1998), to measurement differences between the left and right sides (Blackburn and Knüsel, 2006; Churchill and Formicola, 1997; Kohn and Bennett, 1986; Little et al., 2002; Mays et al., 1999; Plochocki, 2002 and 2004), longbone asymmetry (Jantz and Owesley, 1984; Rhodes and Knüsel, 2005; Ruff and Jones, 1981), dental asymmetry (Guatelli-Steinberg et al., 2006; Harris and Nweeia, 1980; Hershkovitz et al., 1993; Kieser et al., 1986; Schaefer et al., 2006), fingerprint asymmetry (Pechenkina et al., 2000; Reddy, 1999), as well as asymmetry of cranial measurements (DeLeon, 2007; Mooney et al., 1985) and suture closures (Žilvanović, 1983). The inferred implications for these asymmetries also vary, from handedness (Blackburn and Knüsel, 2006, Bradshaw, 1991; Plato et al., 1980), and biomechanical interpretations (Al-Oumaouoi et al., 2004; Churchill and Formicola, 1997; Dutour, 1986; Mays et al., 1999; Plochocki, 2002; Rhodes and Knüsel, 2005) to the result of environmental or socio-historic stress (Albert and Green, 1999; DeLeon, 2007; Harris and Nweenia, 1980; Kieser et al, 1997; Kieser et al., 1986; Kohn and Bennett, 1986; Little et al., 2002; Mooney et al., 1985; Schell, 1981), to being indicators of genetic robusticity and inbreeding (Gibson and Wagner, 2000; Hershkovitz et al., 1993; Pechenkina et al., 2000; Reddy, 1999; Schaefer et al., 2006; Žilvanović, 1983), evolutionary genetics (Baer and Durkatz, 1957, Ernande and Dieckmann, 2004; Guatelli-Steinberg et al., 2006; Houle, 2000; Livshits and Kobyliansky, 1991; Pominankowski, 2004), schizophrenia (Naugler and Ludman, 1996), and other behavioral
problems (Benderlioglu and Nelson, 2004; Benderlioglu et al., 2004; Naugler and Ludman, 1996). This thesis will cover a general overview of each of the types of asymmetry.

There are two key types of asymmetry, directional and fluctuating. Directional asymmetry, or DA, is an asymmetry that affects one side of the body more than the other side. The difference between the right and the larger left ventricle of the heart is one example of genetically pre-programmed directional asymmetry (Hallgrimsson et al., 2002; Waddington, 1942, 1953). Directional asymmetry is associated with studies of handedness and biomechanical loading (Al-Ouimaoui et al., 2004; Blackburn and Knüsel, 2006; Bradshaw, 1991; Churchill and Formicola, 1997; Dutour, 1986; Mays, 1999; Mays et al., 1999; Molnar, 2006; Plato et al., 1980; Plochocki, 2002, 2004; Rhodes, 2006; Ruff and Jones, 1981; Stirland, 1998; Van Valen, 1962; Wilczak, 1998).

The second type of asymmetry is fluctuating asymmetry, or FA, which creates asymmetry favoring neither side of the body. It is the random difference between quantitative measures of a bilateral trait (Fields et al., 1995). Different traits in the same body will favor varying sides. Fluctuating asymmetry is believed to be the result of the inability of an organism to develop along a predetermined path (Debat and David, 2001; Gibson and Wagner, 2000; Hallgrimsson et al., 2002; Van Valen, 1962). Studies of fluctuating asymmetry include discussion on the heritability, evolutionary development, its potential as a mechanism for buffering genetic phenotypic variation and microenvironmental perturbations, general genetic fitness, and evidence for sociocultural or environmental stresses (Van Valen, 1962).
Directional Asymmetry

Researchers observe several general patterns concerning directional asymmetry of most human skeletons. Asymmetry can affect upper and lower limb bones, with one side routinely larger, longer, or heavier than the other side (Ruff and Jones, 1981). There are three main causes proposed for directional asymmetry or DA: developmental predetermination, biomechanical loading and pathological causes. Developmental predetermination proposes that the left side of the body receives more nutrients. This has been documented in all paired bones and exists even at the fetal stage (Plato et al., 1980). This hypothesis is also used to explain the dominance of the left side of the brain. However, there are not many studies based on a developmental origin for directional asymmetries.

Other studies put a greater focus on the second cause of DA: biomechanical loading due to handedness and/or cultural behavior. Structural directional asymmetries can develop through modeling and remodeling of bone because of differential levels of mechanical loading (Ruff and Jones, 1981). Bone can adapt its form in response to the mechanical forces imposed on it resulting in an increase where additional strength is needed and a decrease where it is not needed (Mays, 1999).

The effects of repeated biomechanical differential loading results in directional asymmetry and has been used to infer handedness. Studies of directional asymmetry have contributed much to the study of handedness. Most studies agree that right handedness is the dominant pattern in humans (Blackburn and Knüsel, 2006; Bradshaw, 1991; Plato et al., 1980). Between 85-95% of the population use the right hand dominantly for most activities (Blackburn and Knüsel, 2006; Mays at al., 1999). A sex distinction exists since there are more left handed men than left handed women (Blackburn and Knüsel, 2006; Stirland, 1998). Because of this dominance of right handedness, it becomes easy to look at skeletal populations and study the evidence for
handedness. Asymmetries should be studied for handedness when they occur on a specific side of the body 85-95% of the time (Ruff and Jones, 1981). Conversely, in order to prevent misleading results, directional asymmetry needs to be taken into account in any study where right and left sides are used indiscriminately (Ruff and Jones, 1981).

A biomechanical differential handedness explanation has been put forward for directional asymmetries in both the sacrum and the clavicle. Increased directional loading of the dominant side (generally right) during endochondral bone growth is hypothesized to lead to greater robusticity of that side (Plochocki, 2002). Any deviation from a larger right side is explained as the effect of activity-related movement (Mays et al., 1999). As people age there is a decrease in upper and lower limb asymmetry, mostly as a reduction of the dominant side. This could be explained as an effect of aging, or of a change in behavior and a lightening of work loads associated with aging (Rhodes and Knüsel, 2005).

Even as the majority of the population favors right handedness, there is a tendency to left leggedness. The left femur averages about 1% longer and heavier than the right femur (Ruff and Jones, 1981). Approximately 85% of right-handed young adults had longer left limbs, while the same percentage of left-handed individuals had longer right limbs (Plochocki, 2002).

The sacrum represents the area at the center of transition between the upper body, which is used to lift and carry, and lower weight-bearing extremities. Plochocki (2002) demonstrated statistically significant DA, in his study of 238 individuals from the Hamann-Todd skeletal collection for three sacral measurements. All three measurements consistently demonstrated a larger left side both in height and breadth of the sacrum in right handed individuals. Anatomically it has been observed that the lumbosacral joint incurs greater loading, joint stress and muscle contractions on the opposite side of the loaded arm (Plochocki, 2002). This results in the left side being under greater stress from loads carried in the right arm. The greater the weight the more
robust the osteological response, resulting in the expression of DA caused by repeated asymmetrical loadings on the sacrum (Plochocki, 2002).

In a study of the clavicle, Mays et al. (1999) interpreted directional asymmetry as the result of preferential biomechanical loading. Mays et al. (1999) chose to study the clavicle because it ossifies early, but fuses late. This longer period of development equates to a longer period of time in which mechanical loading can affect its final form. Among the clavicles of adults, a larger degree of asymmetry can then be interpreted as the result of more years of asymmetric loading (Mays et al., 1999). Mays et al. (1999) found that overall, the left clavicle is longer and less robust, than the right clavicle, which is shorter and more robust because compressive biomechanical forces on the dominant side restricted the development of the clavicle (Mays et al., 1999). However, Wilczak (1998) correlated asymmetry of muscle insertion sites to cultural or genetic adaptations to climate, as well as variations in sexual dimorphism.

Evidence of DA is increasingly being used to discover activity patterns among various archaeological populations (al-Oumaoui et al., 2004; Dutour, 1986; Mays, 1999; Molnar, 2006). An example of such a study would be Mays (1999), which compared degrees of asymmetrical differences in the humeri from a medieval assemblage. Examining burials between the 11th and 16th centuries, Mays (1999) found differences between male and female layfolk and between the male layfolk and their religious monks buried in the Fishergate site in York, England, revealing two patterns in the DA. The statistically significant difference between asymmetry levels of the male and female layfolk is interpreted as differential work loads as well as part of human sexual dimorphism. The greater humeral asymmetry in the Fishergate males indicates greater differential loading of the arms in heavier occupations than among Fishergate females (Mays, 1999). This is supported by the historical use of heavy, one-handed tools in medieval craftsmanship. Men were
often apprenticed into a specific lifelong craft resulting in a concentrated use of a single set of tools, while medieval women would be employed intermittently in multiple trades (Mays, 1999).

The second pattern found small differences between the monks and the laymen, which was less pronounced than between the Fishergate females and the laymen. The size of the humerii was significantly different, but the DA was not. Mays (1999) interpreted these results to mean that while the monks lead a quiet ascetic life, they did participate in some tasks which required heavy differential loading. Historical evidence demonstrated that monks in that particular monastery followed the rule of St. Augustine, which recommended study and intellectual pursuits, activities which normally lead to a rather sedentary lifestyle. However, considering that the degrees of workload-related asymmetry was the same for the farmer laymen and the monks, the skeletal collection was interpreted as showing signs that the monks still undertook tasks that at least required differential loading of the upper limbs (Mays, 1999).

Rhodes and Knüsel (2005) proposed that preferential weapons use led to different patterns of robusticity and asymmetry in two blade-injured groups. Using humeral cross-sections the researchers compared two groups of blade-injured British males. One set was from the Towton population, in North Yorkshire, England, which consisted of battlefield casualties from the Battle of Towton, 1461 AD, during England’s War of the Roses, 1455-1487 AD (Rhodes and Knüsel, 2005). The other blade-injured sample came from Fishergate in the city of York, England. This population was from three chronologically separate burial areas each containing individuals from differing socioeconomic levels (Rhodes and Knüsel, 2005). The majority of the blade-injured individuals came from the earliest area, though individuals from all three areas were included in the analysis. A control group of nonblade-injured males from the Fishergate site, was also analyzed (Rhodes and Knüsel, 2005).
For Rhodes and Knüsel’s study (2005), measurements were taken to determine degrees of general robusticity and patterns of cortical bone distribution at 10% increments throughout the humerus. In general, both samples were similar with some notable exceptions. The Towton sample displayed left-side dominance in both cortical bone deposition and robusticity (Rhodes and Knüsel, 2005). The degree and placement of the increased cortical deposition led the researchers to conclude that the distal end of the left humerus was subjected to a higher degree of strain than that of the right humerus. Among the Fishergate samples right-side dominance was demonstrated. These differences along with a consideration of the cultural-historical environment led Rhodes and Knüsel (2005) to conclude that the Fishergate individuals were training with a right-handed unimanual weapon, most likely a sword. The Towton men, on the other hand, were engaging in activities that preferentially loaded the distal left humerus and created a difference in shape from mid-distal to mid-proximal shaft. Based on historical information the Towton men were more than likely using a longbow (Rhodes, 2006; Rhodes and Knüsel, 2005). Fourteenth century English law required all males 7-17 years old to own a longbow and to practice with it. Longbow mastery was so important that other forms of sport were often outlawed (Rhodes and Knüsel, 2005; Rhodes 2006). Mastery of the longbow requires training starting in childhood and while it requires the use of both hands, the left draw arm holds the majority of the weight, which in medieval times was 120 - 150 lbs. (Rhodes and Knüsel, 2005).

Some researchers (Stirland, 1998; Wilczak, 1998) argue against the biomechanical studies of asymmetry. Stirland (1998) and Wilczak (1998) argue that the correlation of specific sites to specific activities should not be used because bone has genetically and environmentally influenced variations in formation including the effects of age, sex, and climate. In addition to unclear definitions of attachment sites, there is an indistinct association between attachment sites and muscle size and subjective scoring of the size of sites.
There are many factors that add to the variation in bone formation. Genetically, not all people form bone to the same extent (Stirland, 1998). Even among the same sex, one female can be more robust than another female, based on a genetic propensity to build bone. “Bone formers” will have a greater amount of bone around the joint margins and other areas (Stirland, 1998). Stirland (1998) argues that two people with the same work load will not present the same amount of bone formation (Stirland, 1998). Cross-culturally, there is a uniformity to the higher degree of right handedness among females (Wilczak, 1998). Wilczak (1998) argues that this uniformity is an indicator of a sex difference originating in development, not in biomechanical use. Additionally, the development of muscle markers increases with age, which can cause misleading results. For example, a population containing a large number of elderly adults will appear more muscular (al-Oumaoui et al., 2004). Age differences in insertion site size have been demonstrated and are not as significant in females as they are in males (Wilczak, 1998). Factors such as habitual stress, and regional variation in genetics also influence the creation of bony insertion sites (Wilczak, 1998).

Another consideration proposed by opponents of biomechanical interpretations is the lack of clarity concerning how attachment sites actually relate to the size of soft tissue and muscle sizes. Stirland (1998) compared an archaeological sample of 100 young adult men (< 30 years) and older adult men (+30 years), to a series of x-ray films taken of physically fit male Navy divers. Stirland (1998) unsuccessfully compared subjective muscle insertion scores with the amount of cortex present at the same site with limited success.

In addition, it is difficult to define an attachment area which leads to questionable repeatability. Scoring of enthesopathies is subjective and numerical values are used to represent a progressive order. A score of 4 is not four times larger than a score of 1 (Stirland, 1998). Stirland (1998) argues that a single muscle cannot lead to conclusions regarding a particular activity since that muscle can be used in a variety of muscle groupings.
The third cause of DA, pathologies, can lead to specific types of asymmetry. One example is adult onset Erb-Duchenne brachial plexus palsy. This condition limits an individual’s mobility at the glenohumeral joint. This limitation still allows for normal use of the forearm. Adult onset Erb-Duchenne brachial plexus palsy results in a directional asymmetry favoring the unaffected arm, but lower levels of asymmetry for the forearms as opposed to the upper arm (Churchill and Formicola, 1997).

When pathology or trauma affects one limb, the other side must then take over for both workloads. Trauma such as a severe fracture may force the disuse of one arm leading to disuse atrophy of the muscles. The result is often hypertrophy of the other limb. Any individual displaying high degrees of marked asymmetry in their limbs should be examined for evidence of trauma (Churchill and Formicola, 1997).

The above discussion demonstrates that DA plays a role in development, handedness, activity patterns and pathological origins and that both the presence of and the lack of DA can be used to infer something about the activity or development of individuals. The response of the body to increased mechanical stress can be influenced by age, sex, genetics, and environment, however an overall response in a singular direction is important to detect when studying past populations and is of interest to bioarchaeologists (al-Oumaoui et al., 2004; Dutour, 1986; Mays, 1999; Molnar, 2006; Rhodes, 2006; Rhodes and Knüsel, 2005).

Fluctuating Asymmetry

While biomechanical and handedness models describe patterns of asymmetry occurring in a single direction, studies of fluctuating asymmetry explore the meanings of asymmetric patterns that do not favor a particular side. These studies examine the effects of environmental stress on the human body and its regulation of development and growth. The literature regarding
fluctuating asymmetry also reveals questions of genetic fitness as well as general health (Debat and David, 2001; Ernande and Dieckmann, 2004; Gibson and Wagner, 2000; Hallgrimsson at al., 2002; Houle, 2000; VanDongen and Lens, 2000).

Genes that code for specific traits do not code differently between sides (Fields et al., 1995; Murray and Gridley, 2006), thus differences between right and left sides are hypothesized to be the result of environmental or genetic disturbances. Fluctuating asymmetry is a potential measure of the degree of stress experienced by an individual, as well as a reflection of the genotype’s ability to compensate for that stress. Studies correlate fluctuating asymmetry with disturbances in environmental factors affecting development such as maternal obesity and smoking (Kieser et al., 1997); loud noise, heat and cold during in utero growth (Mooney at al. 1985; Schell, 1981); maternal diabetes (Kohn and Bennett, 1986) as well as an organism’s zygosity (Livshits and Kobyliansky, 1991; Naugler and Ludman, 1996).

Many studies of fluctuating asymmetry address all types of asymmetry found as well as the possible causes and the meanings of that asymmetry. A good example is Little et al. (2002) and their study of chronically undernourished children in Southern Mexico. Little et al. (2002) examined the environmental and biomechanical implications associated with fluctuating asymmetry in two populations of school children. They compared children living under low socio-economic conditions and chronic undernutrition in Mexico with well-nourished children, and young adults, from an urban middle-class background in Texas.

Little et al. (2002) describe the Mexican children as coming from a small subsistence community with relatively little gene flow resulting in increased inbreeding. Increased asymmetry could be correlated to the homozygosity of the population, a possible result of inbreeding (Little et al., 2002; Hershkovitz et al., 1993). Little et al. (2002) also describe the living conditions of the children to note the high environmental stress the children live with including chronic mild-to-
moderate undernutrition, along with a high infection rate and parasitic load. Many of the children had heights that fell below the fifth percentile, as well as a later age of menarche, which might be due to undernutrition, parasite load, high fevers or infections (Little et al, 2002). Thus, Little et al. (2002) suggests the population was affected by increased childhood environmental stress.

The results of this study were not expected. The analysis found that FA was actually higher among urban Texans, while DA was higher among the undernourished Mexican children. Little et al. (2002) reason that the results could be the product of decreased levels of activity in the undernourished children resulting in a smaller, harder to detect level of asymmetry, or a possibly stronger genetic canalization against fluctuating asymmetry. The authors also posit that intensive unilateral activity could be the cause of the directional asymmetry observed in the rural school children and may obscure the fluctuating asymmetry (Little et al., 2002).

The study by Little and coworkers (2002) demonstrates several of the topics associated with asymmetry, including the different types, the known or hypothesized causes of each type, statistical tests used and the genetic heritability of FA, and is a good introduction to asymmetry studies.

Fluctuating Asymmetry: Environmental or Genetic

Discussions concerning the meaning of skeletal asymmetry converge at the implications of environmental and genetic influences. Fluctuating asymmetry is theorized to be caused by environmental and genetic “noise.” “Noise” is anything that can interrupt the organism’s original developmental telemetry, such as a high fever, infection, malnutrition, or other sources of environmental stress (Kieser et al., 1997; Kohn and Bennett, 1986; Mooney et al., 1985; Schell, 1981; Van Valen, 1962; Waddington 1942, 1953).
Several studies examine the contributions of environmental noise to fluctuating asymmetry (Kieser et al., 1997; Kohn and Bennett, 1986; Little et al., 2002; Mooney et al., 1985; Schell, 1981). Mooney et al. (1985) performed an experiment on in utero rats who were exposed to cold, heat, or noise from conception through parturition. The rats were divided into groups composed of individuals from several different litters, in order to control for genetic influence. The cold-stress group were conceived and born in a 10 °C environment, the heat-stress group developed in a 33 °C environment. The noise stress group they were exposed to random intermittent high-intensity sound for four hours three times a week. The control group were conceived and born at a comfortable room temperature of 22 °C. To control for outside variables, maternal cage size, food and water availability, and a 12-hour light/dark cycle were held constant across all groups (Mooney et al., 1985).

Once at term, researchers sacrificed the mother rats and the neonatal rats’ parietal bone lengths were measured and the data analyzed for evidence of asymmetry. Results show that all three prenatal stressors significantly increase the magnitude of fluctuating asymmetry in parietal bone length when compared to the data from the control animals. For the etiology of this specific effect the researchers hypothesize that a generalized stress syndrome contains the interaction of the pituitary gland, the adrenal cortices, and the parathyroid glands. One of the many effects of the interactions of these glands can lead to lowered amounts of calcium in the circulatory system. Since the developing fetus needs calcium to develop, the stressors caused disruptions in the normal development of the cranial bones (Mooney et al., 1985).

While some researchers focus on the role of environmental “noise” in the development of FA (Kieser et al., 1997; Kohn and Bennett, 1986; Little et al., 2002; Mooney at al. 1985; Schell, 1981), the exploration of the part genetics and genetic “noise” play in FA was the focus of early (Baer and Durkatz, 1957; Livshits and Kobyliansky, 1991; Scharloo, 1991, Van Valen, 1962;
Waddington, 1942, 1953) as well as continuing (Debat and David, 2001; Gibson and Wagner, 2000; Hall, 2005; Hallgrimsson et al., 2002; Naugler and Ludman, 1996), research pertaining to asymmetry. Canalization, phenotypic plasticity, and developmental stability are three regulatory processes that interact, positively and negatively, to resist the effects of genetic and environmental noise (Debat and David, 2001).

Fluctuating asymmetry is more than just the effect on the organism’s phenotype; it is also part of an organism’s genetically preprogrammed response to developmental disturbances. This resistance to developmental noise is called canalization or developmental homeostasis (Van Valen, 1962). Developmental homeostasis can be defined as the ability to produce a consistent phenotype in spite of variable genetic and/or environmental features (Waddington, 1942, 1953).

The result of this resistance is the reduction of the phenotypic effect of a mutation or environmental change (Hallgrimsson et al., 2002). It is also sometimes referred to as genetic buffering since the genes have created a buffer from environmental and genetic disturbances. It is debated as to whether the source of the triggers for the buffering effects are environmental or genetic (Van Valen, 1962).

Canalization is the tendency for development of a specific genotype to follow the same developmental path, no matter the environment or genetic background (Hallgrimsson et al., 2002). Once a developmental pathway is disrupted, what keeps it from spiraling out of control? What brings an organism’s development back on track so that it can survive and pass on its genes?

Waddington (1942), the pioneer of canalization theory, wrote about regulatory processes that were genetically programmed to correct internal and external disturbances. Waddington (1942) created the concept of the epigenetic landscape in which development begins at the top of a valley. Branching valleys along the descending slope represent the numerous possible
developmental pathways, leading to a variety of different ends, or results. The developmental process is visualized as a ball rolling though the valley to its end point. The steeper the walls of the valley, the stronger the trajectory of the ball. Once development gets going, if internal or external disturbances push it off course it will have a tendency to return to its original course (Waddington, 1942). The force pulling the ball back to its original trajectory is hypothesized to be a genetic programming referred to as canalization. The return of development to its predetermined path can be physically demonstrated by the tendency for a “catch-up” period of growth in children whose development was interrupted either because of environmental reasons such as undernutrition, or for health reasons such as cancer or anemia.

Waddington (1953) also pioneered the concept of a genetic threshold. He performed the initial experiment on the wild-type of *Drosophila*. Waddington (1953) exposed generations of developing fruit-flies to heat. His initial unexposed population did not exhibit any signs of the phenotype known as cross-veinless. Waddington (1953) separated and interbred the ones that had the cross-veinless phenotype and the ones that did not show it. In each subsequent generation, he made the same division. After twelve generations a definite pattern revealed itself. The frequency of the reaction increased in the generations bred from the heat shock-induced cross-veinless *Drosophila*, eventually being expressed in over half the generation. The phenotype was reduced in the *Drosophila* lines bred from the selected normal phenotype (Waddington, 1953).

Surprisingly, the cross-veinless type expressed the phenotype even when not induced by heat. In every generation, a few flies were not exposed to the heat shock. In the line selected for increased sensitivity, unexposed flies began to express the cross-veinless phenotype at a higher and higher rate. Waddington refers to this as genetic assimilation and believes that this is due to the Lamarckian inheritance of acquired traits. Others refer to it as a threshold model (Scharloo, 1991).
The threshold model explains the results of Waddington’s experiment as a lowering of the threshold for toleration of mutations because of environmental stress. In any population, there is a genetic threshold level for responses to external stimuli. Part of the population will be above the threshold. The exposure to heat shock lowers that threshold allowing more of the population to transgress it. Selection for individuals with a lower threshold results in a population whose mean threshold is lower than the parental population. After generations of selection for a lower threshold, normal temperatures would create the same effect as heat shock (Scharloo, 1991).

In Waddington’s (1953) study, environmental stress led to a higher percentage of individuals with the mutation. Selective breeding for higher sensitivity to stress led to a higher percentage of the population with the mutation, with or without the stress. Waddington suggests that canalization is the consequence of systems of genes interacting with the environment (Waddington, 1942, 1953).

Developmental stability is the capability for stable development under given conditions. It can refer to buffering systems that reduce the variation resulting from developmental accidents (Debat and David, 2001). A lack of developmental stability could result in homozygous individuals exhibiting heightened fluctuating asymmetry (Hall, 2005). The Drosophila flies displayed developmental stability. While the flies exposed to heat shock did produce a different phenotype, they were still viable organisms able to breed and pass on their genes.

When developmental stability is interrupted, canalization is theorized to bring development back on course. In order to assess this model, Baer and Durkatz (1957) examine the developmental asymmetry in the hands and wrists of children. Four hundred and seventy four x-rays of both hands and wrists were taken of a sample of mostly Caucasian children from middle and upper class families. All the children were in good health and none had any apparent skeletal pathology. Baer and Durkatz (1957) looked at the carpals, the metacarpals and the phalanges. An asymmetry
was found to exist when the same bone was given different stages in each hand (Baer and Durkatz, 1957).

In both sexes, the carpal bones show the highest percentage of asymmetry. A t-test shows that there is no significant sex difference in the total mean percent of asymmetry, nor was one hand significantly advanced over the other. The asymmetry fluctuates with no specific centers of ossification exhibiting asymmetric patterns. Baer and Durkatz (1957) conclude that the asymmetry that occurs in a population of normal children is a result of variability in ossification timing (Baer and Durkatz, 1957). Even among children who have had little to no serious environmental stress, a small degree of FA is still within natural variation.

Even though the ossification timing was different, all the carpal bones developed along the same lines displaying canalization of the developmental sequence. Associated with the canalization of a sequence is morphological integration. This refers to the tendency for structures that are related by a shared developmental process to function or vary in similar ways (Hallgrimsson et al., 2002). The previously described fetal rat experiment is a good example of morphological integration when both sides of the parietal bone were affected by the stress to their shared developmental system (Mooney et al., 1985).

Studies continue to question the heritability of developmental stability and buffering mechanisms in general (Ernande and Dieckmann, 2004; Houle, 2000; Van Dongen and Lens, 2000). Quantitative genetics investigates the questions concerning genetic constraints on the evolution of physical reactions to environmental noise, the development of a buffering system, and considers ecological conditions which might promote the evolution of phenotypic plasticity (Ernande and Dieckmann, 2004; Houle, 2000).

Ernande and Dieckmann (2004) created a computer model to explore the contribution of competitive interactions between individuals of the same species, and from predators, in the
development of phenotypic plasticity. Their model found that plasticity can be influenced by environment and that different phenotypes can occur even in an inbreeding population. The success of a phenotype is dependent on which other phenotypes are present in the population. Interactions between individuals can drive the evolution of phenotypic plasticity. This competition between different phenotypes, even if the genotype is identical, is important to quantitative models of the evolution and inheritance of phenotypic plasticity (Ernande and Dieckmann, 2004). Ernande and Dieckmann’s (2004) computer model included the costs of phenotypic plasticity, a consideration of rich and poor environments, and competition between individuals, and discovered that the evolution of plasticity is more pronounced in environments that are poor in resources. Overall, the researchers found that plasticity can evolve as a trait, sensitive to the environment and changing within the environment. Phenotypic plasticity is sensitive to maladaption, creates few costs, and is promoted in areas of low resources (Ernande and Dieckmann, 2004).

As a trait, phenotypic plasticity is variable and its evolution is difficult to study. Genetically, we have learned that the same gene can have a different phenotypic effect in different animals (Murray and Gridley, 2006). An example is the Snail family genes. Snail (Snai1) and Slug (Snai2) genes have been found to induce neural crest progenitor cells in embryonic frogs and birds. In mice, the exact same groupings of genes do nothing towards creation, delamination, or migration of neural crest progenitor cells. Mice embryos that are deficient in the Snai1 and Snai2 genes have no neural crest deficiencies. They do, however, exhibit asymmetry in their embryonic development favoring the left side. This result of a deficiency of the Snai1 and Snai2 genes shows that genetics plays a role in the left/right symmetry of the embryonic mouse (Murray and Gridley, 2006).
Canalization, developmental stability, and morphological integration are theorized to work together to both stabilize an organism and to increase evolutionary variability leading to developmental homeostasis (Debat and David, 2001; Gibson and Wagner, 2000; Hallgrimsson et al., 2002). Variability is created from a balance of chaos and order. On the side of chaos are processes that create variation: mutations, developmental errors, and environmental effects. On the side of order are systems that attempt to regulate the developmental process, such as buffering and canalization (Debat and David, 2001). For a complex organism to develop into a functionally integrated system, its development needs to proceed along a predictable pathway. Canalization keeps development predictable and the pathway clear (Debat and David, 2001; Hallgrimsson et al., 2002; Waddington, 1953). Variations in development can disrupt this integration and cause an organism to fail. Canalized responses to the environment developed as a method to assist the organism in responding to and surviving the environmental disruptions (Debat and David, 2001; Hallgrimsson et al., 2002; Scharloo, 1999). Therefore, processes that minimize phenotypic variation contribute to the canalization and developmental stability of that trait (Hallgrimsson et al., 2002). Developmental stability means that a trait is stable enough to continue to develop in a steady manner under a variety of environmental circumstances (Debat and David, 2001; Hallgrimsson et al., 2002).

While variation is not supported by canalization, processes that alter the direction of variation contribute to the morphological integration of a trait. Morphological integration is the tendency for traits to co-vary as the result of common development (Hallgrimsson et al., 2002). When developmental stability is decreased there is the potential for an increase in phenodeviants, as the threshold experiment of Waddington (1942, 1953) showed. Developmental homeostasis is the degree to which an organism’s genotype will develop into a phenotype in response to environmental disturbances (Albert and Green, 1999; Debat and David, 2001; Hallgrimsson et al.,
Natural selection favors mechanisms, such as canalization, that allowed organisms to resist the effects of environmental insults and at the same time respond adaptively to those insults (Hallgrimsson et al., 2002).

While Debat and David (2001) and Hallgrimsson et al. (2002) see canalization as a positive mechanism of evolution, other evolutionary geneticists, such as Gibson and Wagner (2000) disagree with the evolutionary need for canalization. Gibson and Wagner (2000), point out that canalization reduces variation, which in turn reduces the capacity for evolution to impact that trait. They state that persistent canalization will stagnate the phenotype of a species leading to macro-evolutionary stasis. On the other hand, there are those biologists (Debat and David, 2001; Hallgrimsson et al., 2002) who believe that the reduction of the effects of new mutations caused by canalization can allow a build-up of hidden genetic variation. In a situation where the canalizing system breaks down, either as a result of ecological circumstances, or admixture of new variation, the hidden variation can no longer be hidden and results in a rapid phenotypic transformation of the population (Gibson and Wagner, 2000; Hallgrimsson et al., 2002). Each individual, with a variable ability to buffer canalization, will have a different phenotypic outcome from the same stressor (Naugler and Ludman, 1996).

Some traits, however, are more prone to variability. As exemplified in Waddington’s *Drosophila* experiment (1953), while a phenotype may have a propensity to change with environmental stress, that does not obligate it to change. The developmental stability, homology, and complexity of the trait will influence the tendency for a trait to fluctuate. The less developmentally stable a trait, the more fluctuating asymmetry it will show (Albert and Green, 1999; Debat and David, 2001; Hallgrimsson et al., 2002; Naugler and Ludman, 1996). Traits which are developmentally homologous within a species display a lower FA in an individual (Livshits et al., 1998). This means that traits that are developmentally similar in most humans will
be less likely to be asymmetrical. In addition, the more complex a trait, the lower its asymmetry (Livshits et al., 1998). This is because the fluctuating asymmetries of the simple traits that make up the complex one will balance out for overall symmetry (Livshits et al., 1998). In this manner, we can observe the function of FA’s buffering mechanisms.

Organisms whose genetic loci contain a majority of heterozygous allele pairings are positively correlated with lower FA. Conversely, homozygous pairings increase the chances of FA (Livshits and Kobyliansky, 1991). This could be because in a homozygous pairing, more recessive genes have the possibility of being expressed, or because of the existence of some hyperdominant genes that express their trait to a greater degree in homozygous pairs (Livshits and Kobyliansky, 1991; Naugler and Ludman, 1996).

Homozygosity is often interpreted as lowering the ability of the body to compensate for environmental stresses, indirectly increasing the effects. Heterozygosity can also be termed, “hybrid vigor,” suggesting an interpretation of hardiness in more exogamous organisms (Hall, 2005).

In humans, the effects of genetics on FA are often explored by studying groups with more homozygous populations, such as endogamous or inbred groups and/or isolated populations (Palmer and Strobeck, 1986). A good example is a study by Schaefer at al. (2006) comparing the dental asymmetry of an isolated Croatian island population from the island of Hvar, in the eastern Adriatic, with that of a modern urban population in mainland Croatia. The island of Hvar, has an unusually high inbreeding coefficient, in some villages 40% of the population are in isonymous marriages. This degree of inbreeding makes it a perfect environment for researching the effects of inbreeding on fluctuating asymmetry. The control sample consisted of residents of Zagreb, the urban capital of Croatia. Residents of Zagreb have ready access to medical and dental care, while the island population is medically underserved. In order to control for the effects of
environmental stress, outbred individuals who lived under the same medically underserved conditions as inbred individuals on the island of Hvar, were used as an additional comparation group. Schaefer et al. (2006), expected the island population to have higher FA because of the genetic inbreeding, exacerbated by the environmental stress resulting from lack of regular dental and medical care.

The researchers made dental casts and sorted them into three groups, island inbred, island outbred and urban. The dental samples displayed a developmental range containing early mixed to complete permanent dentitions. Using previous ethnographic studies, individual children’s casts were assigned an “inbreeding coefficient” based on the degree of their grandparent’s inbreeding. The samples were divided into four groups, three for the island population (an outbred group, a low endogamy group, and a high endogamy group) and one for the outbred urban sample (Schaefer at al., 2006). Using a 3D analysis based on Procrustean superimposition, Schaefer et al. (2006) first explored age and sex related asymmetry, both directional and fluctuating, within each of the three samples and found no significant correlations. To discover the effects of the environment, Schaefer at al. (2006) compared the outbred island group to the urban group and found a pattern of increased FA among the island samples. This level of FA was higher than the level detected when testing for the effects of inbreeding. When the outbred island group was compared to the inbred island group, FA was seen to increase with the degree of endogamy (Schaefer at al., 2006). Schaefer et al.’s study (2006) concluded that FA was significantly higher among the endogamous islanders from Hvar than in urbanized Zabreb, and that FA increases with the degree of inbreeding (Schaefer at al., 2006).

This study supported the position that homozygosity lowers the ability of the body to compensate for environmental stresses, indirectly increasing the effects of FA (Hall, 2005). Homozygosity carries with it a heightened chance for recessive genes to express themselves in
the phenotype, and also lowers the body’s ability to canalize its development. However it is the less developmentally stable traits, which will exhibit increased FA (Albert and Green, 1999; Debat and David, 2001; Hallgrimsson et al., 2002; Naugler and Ludman, 1996).

While inbreeding interferes with canalization, it is possible that the increase in recessive pairing is part of the build-up for hidden genetic variation that Debat and David (2001), and Hallgrimsson et al. (2002) theorized would be exposed when canalization breaks down. Ernande and Dieckmann (2004) found that phenotypic plasticity is promoted in areas of low resources such as the island of Hvar. Natural selection favors mechanisms, such as canalization, that allow organisms to resist the effects of environmental insults and at the same time adapt to those insults (Hallgrimsson et al., 2002).

Fluctuating Asymmetry: Environmental Stress

It is from these studies concerning the inheritance of plasticity and the environmental effects of stress on the developing skeletal system (Debat and David, 2001; Hall, 2005; Hallgrimsson et al., 2002; Livshits et al., 1998; Livshits and Kobyliansky, 1991; Naugler and Ludman, 1996; Palmer and Strobeck, 1986; Schaefer at al., 2006) that asymmetry has been pursued as an indictor of sociocultural and/or environmental stress (Albert and Green, 1999; DeLeon, 2007; Harris and Nweenia, 1980; Kieser et al, 1997; Kieser et al., 1986; Kohn and Bennett, 1986; Little et al., 2002; Mooney et al., 1985; Schell, 1981). While there are possible genetic influences to disruptions of developmental patterns, it is the environmental disturbances that are seen as having a greater contribution to fluctuating asymmetry. A good example of a study that examines the effects of environmental disturbances is by Kieser and coworkers (1997).

Kieser et al. (1997) studied degrees of dental asymmetry in the first permanent molar among children of four different groups of pregnant women. These groups were composed of smokers
and non-smokers, obese and non-obese mothers. Obesity in this study was defined as being in excess of 30 on the Quetelet’s body mass index, used for determining expected weight based on height. Smoker status was defined as smoking more than 20 cigarettes a day (Kieser et al. 1997).

Kieser et al. (1997) reported that previous research had shown that obese mothers show significantly higher incidences of gestational hypertension, miscarriages and high neonatal birth weight. The researchers hypothesized that in addition to the already recognized negative health issues associated with maternal obesity, such as hypertension and diabetes, the increase in fetal morbidity among obese women could also be explained by fetal environmental destabilization while in utero. If the fetus is negatively impacted by the mother’s obesity, fluctuating asymmetry should be able to reflect the degree of fetal destabilization (Kieser et al. 1997).

Among the children of obese-non-smoking mothers, obese-smokers, lean non-smokers and lean smokers, it was the children of the obese mothers overall and obese smokers in particular who showed significantly elevated degrees of FA. Although both groups displayed elevated FA, the dental asymmetry of the children of obese smokers ranked higher than the asymmetry of obese non-smokers. Surprisingly, lean women, whether they smoked or not, did not produce significantly more asymmetries (Kieser et al., 1997).

While obese women are given to higher levels of difficulties giving birth, asymmetry is the result of developmental disturbances, not delivery difficulties. It appears from Kieser et al.’s study (1997) that maternal obesity upsets the developmental homeostasis or canalization threshold of the developing fetus. Since lean moms, whether they smoked or not, did not show any significant differences; then the cigarette smoke may have an additional destabilizing effect creating the difference between the obese smokers and the obese non-smokers. This study highlights the effects of environmental disturbances and found that one disturbance can cause
another to have a greater effect on canalization. The result is a cumulative effect on asymmetry (Kieser et al., 1997).

A study by Kohn and Bennett (1986) looked at the effects of maternal diabetes on the dental FA in two samples of fetal rhesus macaques. One sample was composed of 19 fetuses from diabetic mothers, the other was of 20 fetuses from non-diabetic mothers. Considering that the diabetic mothers were already under biological stress from their diabetes it was not surprising to find that their fetuses exhibited increased FA compared to normal fetuses. Kohn and Bennett (1986) also found that there was increased dental asymmetry in their distal dentition.

Albert and Green (1999) proposed that bilateral differences in the timing of epiphyseal closures could be used as an indication of stress. In order to test this hypothesis, they used two cemetery populations, one population was from an earlier medieval cemetery (550 - 750 AD), while the other was from a later medieval cemetery (750 – 1450 AD) in Kulubnarti, Nubia. A total of 90 individuals ages 11 to 31 comprised the two samples. Thirty-six young individuals were from the earlier cemetery, while 54 were from the late Christian cemetery (Albert and Green, 1999).

Kulubnarti is an island adjoining the west bank of the Nile in Sudanese Nubia. It lies between the second and third cataract in Upper Nubia, in an isolated area filled with rocks and rapids. The site was occupied throughout the entire Christian period and may have been the last Christian settlement before the transition to Islam (Albert and Green, 1999; Hummert and Van Gerven, 1983).

A previous study by Hummert and Van Gerven (1983) documented the diachronic changes in growth patterns as related to the differences in mortality from the two cemeteries. This study (Hummert and Van Gerven, 1983) also documented the biological stress of the two cemetery samples using growth analysis and the occurrence of cribra orbitalia, presenting evidence for
healthier growth patterns in the later Christian cemetery. The osteological paradox also reminds us that these individuals’ lives were cut short by death, suggesting that the individuals studied failed to thrive and survive (Wood et al., 1992).

Albert and Green (1999) chose their research populations within the same geographic area in order to control for normal human phenotypic variation. The two sites were chosen based on information gained through historical documents. By choosing two sites from the same populations the researchers hoped to have a continuous lineage with a more controlled gene flow, as opposed to two sites from entirely different populations. The earlier site historically suffered from considerably greater stress than the later population (Albert and Green, 1999).

Historical analysis suggested that a weakened Christian church combined with a fragmented Christian kingdom led to an increase in regional autonomy in the late Christian period (750-1450 AD). It is hypothesized that this increase in regional autonomy may have brought about a positive change in the health status of the later Christians (Hummert and Van Gerven, 1983).

Albert and Green (1999) tested the usefulness of fluctuating asymmetry for indicating elevated or lowered levels of socio-environmental stress. To this end they documented the stages and progression of epiphyseal union from paired bones in both early and late cemetery samples. While Albert and Green were aware of studies such as Baer and Durkatz (1957), which showed that the same bilateral trait could show variation in the timing of maturation, they felt that if this variation reached a statistically significant level, then it might be evidence of environmental disturbances. Albert and Green (1999) chose to use epiphyseal union because it would reflect socio-environmental stressors that impacted the individuals in their childhood and adolescence.

Albert and Green’s (1999) results from their paired sample t-tests showed that there were statistically significant differences in bilateral asymmetry for the entire sample of 90 individuals. Once the sample was sorted by cemetery, the later Christian cemetery did not exhibit significant
asymmetry, whereas the earlier one did. Albert and Green (1999) showed through the statistical analysis of bilateral epiphyseal union asymmetry that the earlier population displayed higher evidence for environmental perturbations than the later population.

DeLeon (2007) examined the same population utilizing three dimensional morphometric analyses of the skull to evaluate and eventually support the conclusions reached by Albert and Green (1999). DeLeon looked at significant degrees of fluctuating asymmetry, as well as exploring traits that appeared more sensitive to fluctuating asymmetry. Using 30 individuals from each population, with an equal number of men and women, DeLeon (2007) compared 48 measurements from biologically relevant coordinate landmarks on the skull.

DeLeon (2007) discovered that 39 of the total 346 linear distances demonstrated significantly different levels of fluctuating asymmetry between the early population and the later population. Of those linear distances 62% of them were significantly asymmetrical in the earlier, more stressed group, while only 38% were asymmetrical in the later group. The results supported the hypothesis that fluctuating asymmetry reflects levels of environmental stress (DeLeon, 2007).

Kieser et al. (1986) detailed individual differential responses to external stressors as correlated to genetic canalization, by comparing two very different populations. Using dental casts, Kieser et al. (1986) compared the teeth of Lengua Indians from the Gran Chaco region of Paraguay with those of 125 contemporary EuroAmerican individuals.

The Lengua Indians live in an environment of high environmental stress. Their population suffers from high malnutrition and illness with children being the most vulnerable. Illness can exacerbate the already high level of malnutrition by illness-induced anorexia which affects over 70% of the population in their first five years of life (Kieser et al., 1986). The EuroAmerican population lived a much easier life. The affluent White Texan sample was drawn from a population that consumes a high caloric and protein diet. Compared to the Lengua populations
their disease load was much smaller with lower childhood morbidity and a low incidence of infectious disease deaths (Kieser et al., 1986).

Keiser et al.’s (1986) results showed a higher overall level of fluctuating odontometric asymmetry among the more endogamous and environmentally stressed Lengua populations. The data supported the researchers’ predictions that the incidences of dental asymmetry would be much lower for the European population because of their lowered ecological stress (Kieser et al., 1986). As expected, the Lengua Indians had a higher mean asymmetry. However, the Caucasoid population had more individuals with lower degrees of asymmetry. The data demonstrated a bimodality of buffering ability among the European Caucasoid population. It was only in the more dramatic degrees that the Lengua Indians display a higher frequency of asymmetry. This bimodality in a relatively disease-free, nutritionally advanced population shows some individuals do not canalize as well as others even in a advantageous environment (Kieser et al., 1986).

Fluctuating Asymmetry: Behavior

Studies correlating FA and behavior begin by studying the effects of environmental disturbances on the development of a human fetus, then correlating those effects with behavior in the developed child (Benderlioglu and Nelson, 2004; Benderlioglu et al., 2004, Pechenkina et al., 2000). The younger a fetus is, the greater the affect of disturbances on its development (Benderlioglu and Nelson, 2004; Benderlioglu et al., 2004, Pechenkina et al., 2000). Since perturbations experienced during ontogeny can leave lasting signs on the adult body as physical asymmetries, the extent of these disturbances can be studied (Benderlioglu and Nelson, 2004; Benderlioglu et al., 2004, Pechenkina et al., 2000). Human babies develop their fingerprints by the second trimester of gestation. Any developmental fingerprint asymmetries will have to have been created by stressors before that time period (Pechenkina et al., 2000). If a fetus’
development is disturbed early enough, perhaps in the first trimester of gestation, the asymmetries created would have a greater affect on its phenotype, including the nervous system, than later developmental disturbances (Pechenkina et al., 2000). This has led some researchers to connect asymmetry with certain behavioral disorders (Benderlioglu and Nelson, 2004; Benderlioglu et al., 2004, Pechenkina et al., 2000).

Studies have linked high FA with schizophrenia, attention deficit disorder (ADD), as well as developmental delays and Down syndrome (Benderlioglu and Nelson, 2004; Naugler and Ludman, 1996). Additionally, some researchers have connected fluctuating asymmetry with aggressive behavior (Benderlioglu et al., 2004). These researchers (Benderlioglu et al., 2004) hypothesize that neurological damage would lead to poor impulse control. When provoked, both men and women with higher degrees of FA responded in a more aggressive manner than those with lower degrees of FA (Benderlioglu et al., 2004). However, aggressive behavior is difficult to define. The correlations between FA and behavior are in need of further research before any conclusions can be definitive.

Fluctuating Asymmetry: Conclusion

In conclusion, there are many biological conclusions that can be formed from studies of directional and fluctuating asymmetry. DA’s role in development, handedness, activity patterns and pathological origins have been examined (al-Oumaoui et al., 2004; Blackburn and Knüsel, 2006; Bradshaw, 1991; Churchill and Formicola, 1997; Mays, 1999; Mays et al., 1999; Plato et al., 1980; Plochocki, 2002; Rhodes and Knüsel, 2005; Ruff and Jones, 1981; Stirland, 1998; Wilczak, 1998). The response of the body to the environment in a singular direction is important to detect when studying past populations and is of interest to bioarchaeologists (al-Oumaoui at al., 2004; Dutour, 1986; Mays, 1999; Molnar, 2006; Rhodes, 2006; Rhodes and Knüsel, 2005).
The FA of various traits including teeth, epiphyseal union, suture closure, and finger prints have been used to test for environmental disturbances at individual and population levels (Guatelli-Steinberg et al., 2006; Harris and Nweeia, 1980; Hershkovitz et al., 1993; Žilvanović, 1983). The literature regarding fluctuating asymmetry also reveals research questions addressing genetic fitness as well as general health (Debat and David, 2001; Ernande and Dieckmann, 2004; Gibson and Wagner, 2000; Hallgrimsson at al., 2002; Houle, 2000; VanDongen and Lens, 2000).

Researchers have drawn conclusions from these studies on canalization levels, socio-environmental stress, sexual selection behavior and mental instability (Albert and Green, 1999; DeLeon, 2007; Hummert and Van Gerven, 1983; Kieser at al., 1986; Kieser et al. 1997; Kohn and Bennett, 1986; Møller, 1993, 1999; Palmer and Strobeck, 1986). Even though some of these applications, such as aberrant behavior, are currently under scrutiny, research continues (Benderlioglu and Nelson, 2004; Benderlioglu et al., 2004, Pechenkina et al., 2000). Future conclusions will confirm or deny the usefulness of these studies. Whether influenced by genetics or behavior, asymmetry continues to be useful for gaining information from human skeletal populations.
Chapter 3

LITURATURE REVIEW: ARIKARA

Geographic and Temporal Designations for the Arikara

This study evaluates data collected from three Arikaran Native American protohistoric cemetery sites, Leavenworth Village cemetery, Larson Village cemetery, and Mobridge Village cemetery, located along the middle portion of the Missouri River in the northern counties of present day South Dakota, USA (Blakeslee, 1994).

Archaeologically, these sites are classified as belonging to the Coalescent Tradition, which includes all sites north of the South Dakota-Nebraska Border and all protohistoric sites in the Central Plains area. The Coalescent Tradition is further subdivided into four temporal variants: the Initial Coalescent Variant (C.E. 1400 – C.E. 1550), the Extended Coalescent Variant (C.E. 1550-1675), the Postcontact Coalescent Variant (C.E. 1675-1780) and the Disorganized Coalescent Variant (C.E. 1780-1862) (Blakeslee, 1994; Lehmer and Caldwell, 1966; Rogers, 1990).

It is believed that prior to the Coalescent Tradition the Arikara descended from tribes further south on the Central Plains who were part of the Central Plains Tradition (Blakeslee, 1994; Rogers, 1990). The migrating populations initially settled along the Missouri River in northern Nebraska and South Dakota displacing members of the archaeologically denoted Middle Missouri Tradition, the ancestors to the Mandan Tribe (Blakeslee, 1994; Ubelaker and Jantz, 1979). These early sites and populations are archaeologically designated as the Initial Variant of the Coalescent Tradition (C.E. 1400 – C.E. 1550). The region the Arikaran people moved to is referred to as the Upper Missouri in historical and ethnohistorical studies, but is named the Middle Missouri in archaeological literature (Blakeslee, 1994; Rogers 1990).
Materially, changes from the Central Plains Tradition into the Initial Variant of the Coalescent Tradition are marked by changes in house forms from square to round and by the addition of grooved mauls and simple vessel stamping (Blakeslee, 1994). Culturally, it is marked by an increase in warfare, substantiated by an increase in fortifications around settlement areas (Blakeslee, 1994; Rogers, 1990). Good quality agricultural land is scarce in the Middle Missouri Region. As the Central Plains horticulturalists moved into the Middle Missouri, the need to defend their limited farming land increased (Blakeslee, 1994; Rogers, 1990). As a result, villages in the middle Missouri regions were concentrated into defensible units (Blakeslee, 1994).

While the movement of people and material culture in the Initial Variant is observable by archaeologists, the reasons for this movement are not. Some researchers believe that the Central Plains drought of 1539 to 1564 is the cause for the migration of an entire geographic region (Lehmer, 1954, 1971). Radiocarbon dates however pushed the dates for the beginning of the variant earlier, causing some researchers to invoke the Pacific I climate episode as the cause for the invasion of the Arikara further north than the Central Plains (Blakeslee, 1994).

As the Arikaran population of the Extended Coalescent Variant (C.E. 1550-1675), continued to move north, their sites began to dominate the Missouri trench in South Dakota (Blakeslee, 1994). These sites are marked by their smaller size as well as shorter periods of occupation and a lack of fortification (Blakeslee, 1994; Rogers, 1990). It is possible that this pattern of occupation increased the number of sites, artificially creating an archaeological perception of a larger population than actually existed (Blakeslee, 1994). In addition to being smaller, they are also less fortified than the Initial Coalescent and more widely spaced (Blakeslee, 1994). The lack of fortifications seems to indicate a period of peace: archaeologists of the River Basin Surveys referred to it as the “Pax La Roche”. The peace may be an indication of the end of the Coalescent population’s adjustment to their new territory, which they now dominated (Blakeslee, 1994).
The Postcontact Coalescent Variant (C.E. 1675-1780) is delineated archaeologically by the presence of European trade goods (Blakeslee, 1994; Rogers, 1990). Beginning in 1675, the Postcontact Coalescent lasts about 100 years until 1780. The earliest European trade items are found as grave goods rather than as refuse in the habitation areas, possibly an indication of a spiritual association between early Euro-Americans and their goods (Rogers, 1990). As time continues there is a marked increase in European goods found in the village areas (Blakeslee, 1994). While a site is considered part of the Postcontact Coalescence if it contains trade goods, trade goods do not mean that actual European contact had been made. The Arikara are known to have received European goods through other Native American tribes (Rogers, 1990).

During the Postcontact Coalescent Variant an increase or a return to a pattern of intense warfare is hypothesized as settlements are once again heavily fortified (Blakeslee, 1994). In this historic period, the factors for warfare are a little better understood. A thriving slave trade preceded the arrival of the Europeans and decreased a population already negatively affected by epidemics such as smallpox (Nasatir, 1952). The migration of new groups into the area spurred by European expansion and disease, as well as the introduction of European horses and guns gave the people more mobility as well as increased the damage from warfare (Blakeslee, 1994). The Arikara would have gained horses at least by 1738 and guns by 1750, just in time for them to have gained mastery of the horse before the Sioux moved in around 1750. The Sioux continued to harass Arikara trade, hunting, and village life until 1770 (Blakeslee, 1994). By the end of the Postcontact Coalescent Variant the Arikara were firmly placed as horticulturalists and middlemen participants in the economics of the fur trade.

As early as the 1600’s French explorers and traders surveyed the lower reaches of the Missouri River, but never made it to Arikara territory (Nasatir, 1952). In 1704, a survey of tribes living along the river did not mention any tribes from the upper Missouri, including the Arikara.
It is not until 1714 that the presence of Arikara villages is noted (Giraud, 1953). By 1719 explorers were conscious enough about the economics of the area to notice that the Arikara were being raided by the Osages and Missouris for slaves (Nasatir, 1952).

The Europeans who contacted the Arikara were not representatives of any one nation, but were traders from various European countries, including Spanish, French, and English trappers searching for beaver and buffalo pelts (Rogers, 1990). Representatives of the USA such as Lewis and Clark did not arrive until after the sale of the Louisiana Purchase (1803) in the Disorganized Variant in 1804-1805 (Rogers, 1990).

The Disorganized Coalescent Variant (C.E. 1780-1862) denotes a period in which European contact and the consequences of that contact intensified the Arikara environmental landscape. The variant begins in 1780 and continues for eighty years until 1862 (Rogers, 1990). Within twenty years of the beginning of the Variant, the Louisiana Territory was purchased from France by the American president, in 1803. President Thomas Jefferson’s Corps of Discovery, led by Meriwether Lewis and William Clark, explored the new territory from 1804 – 1805. This exploration began a new era of expanded trade and contact between the Arikara and Euro-Americans (Rogers, 1990).

Most of the new trade potentials were not in the Arikaran’s favor (Rogers, 1990). American fur companies attempted to bypass the Arikara middlemen as they pushed further up the river to trap a diminishing number of beavers. In 1822, the major trapping companies began to send White trappers out to do the work that formerly was done by Indian trappers and middlemen (Rogers, 1990). In addition to a limited catch, the European vogue for beaver furs was declining, decreasing the value of the ones that were trapped (Rogers, 1990). The escalation of Arikara violence in this time period coincides with decreased demand for furs and the decreased power of the Arikara to participate in intratribal trade (Rogers, 1990).
In addition to the economic stress imposed by the limitations on their trade capability, the Sioux began to harass the Arikara in earnest in 1805. The Arikara had been hit with outbreaks of smallpox in 1801-1802 and again in 1818-1819 (Rogers, 1990). The results of this rapid depopulation decreased the Arikara’s ability to protect themselves. As one of the nomadic tribes, the Sioux were less affected by smallpox epidemics, a situation they took full advantage of. Jean Baptista Trudeau, a French explorer noted that the Sioux stole the Arikara’s horses, and that they beat the women and insulted the Arikara in any way they could. He also noted that they diverted the bison away from Arikara villages (Abel, 1939). This harassment along with the loss of income must have contributed to the Arikara’s decision to relocate in 1832 (Rogers, 1990).

Depopulation from smallpox and other communicable diseases may have decreased the Arikara’s ability to defend themselves from enemies, as well as secondary infection. Starvation compromises the immune systems, increasing the death toll from the next epidemic (Calloway, 1999; Rogers, 1990). In view of their dwindling ability to supply enough food to feed them, the Arikara left the Missouri Valley and moved in with their cousins, the Pawnee, on the Loup River (Rogers, 1990).

Immediately after the Arikaras’ return to the Missouri River Basin four years later in 1836, they were hit with a devastating smallpox epidemic from 1837-1838 (Trimble, 1994). While this was not the first epidemic it is considered to be one of the most devastating because of the vast territory it affected.

In May of 1837, the crew of a steamboat owned by the American Fur Trading company experienced an outbreak of smallpox (Trimble, 1994). The outbreak quickly spread to the other passengers including Native Americans traveling to visit family and friends along the Missouri River Trench. The steamboat captain, fearing delays in his provisional deliveries, refused to quarantine the passengers (Trimble, 1994). Disembarking passengers came into contact with
people at every single port of call. The first smallpox deaths were reported on July 1, 1837 in three separate places (Trimble, 1994). Within weeks the Arikara of Fort Clark were infected by two Arikara women who came to visit relatives (Trimble, 1994).

The pestilence spread quickly. Between the first week of May, when the passengers of the ship was diagnosed, and the third week of June, the smallpox affected almost every tribe along the Missouri Trench (Trimble, 1994). The epidemic lasted for three to seven months along the Missouri River affecting the area from Fort Leavenworth, Kansas, to Fort Union in the northern area of North Dakota (Trimble, 1994). The resulting widespread depopulation was consuming and profound. At Fort Union ten out of twelve Indians were reported dead. One Mandan village went from a population of 600 to 14 survivors (Trimble, 1994). It is estimated that seven-eighths of the Mandan and one-half of the Arikara died in the Smallpox Epidemic of 1837-1838 (Trimble, 1994).

The end of the Disorganized Coalescent Variant brought some economic respite to the devastated Arikara tribes of the upper Missouri (Abel, 1939). Their return to the Missouri placed them back within the trade network as middlemen. The 1830’s brought an increase in the demand for bison hides, which the Arikara hunted when not being harassed by the Sioux, and traded for food and supplies (Abel, 1939). This improvement, however, was not enough to supply enough food for the Arikara to survive. By the end of the Disorganized Coalescent, the Arikara were obliged to accept annuities from the United States Government Indian Agents (Rogers, 1990).
Site Descriptions

Mobridge

The Mobridge site consisted of a village and three burial areas. The site was located on the north bank of the Missouri River, west of modern day Mobridge City in Walworth Country, South Dakota and is denoted by the trinomial 39WW1 (Merchant and Ubelaker, 1977). The site is dated from 1600-1650. The Arikara occupied the site during two different occupations (Owsley et al., 1982). William M. Bass of the University of Kansas directed the excavations during the summers of 1968 – 1971. The entire cemetery sample consists of 654 skeletons (Merchant and Ubelaker, 1977).

The first occupation of Mobridge occurred during the Extended Coalescent Variant while the second occupation occurred during the Post-contact Coalescent Variant. These separate Arikara occupations are referred to as Mobridge I and Mobridge II (Owsley et al., 1982). The three burial areas are referred to as Features 1, 2, and 3. Feature 1 is on a small hill west of Mobridge Village. Feature 2 is on a large long hill about 200-300 yards south of Mobridge Village. Feature 3 is on a small knoll about 100 yards south of Feature 1 (Merchant and Ubelaker, 1977; Owsley et al., 1982).

The internal chronology of the three features was established archaeologically by the presence of European trade goods (Merchant and Ubelaker, 1977; Owsley et al., 1982). Features 1 and 3 contained very few European trade goods, leading archaeologists to establish a date within the Extended Coalescent Variant, before 1675. Grave goods from Feature 2, however, demonstrated a Post-contact Coalescent Variant temporal designation. Roughly 20% of grave goods from Feature 2 were of European origin, suggesting a date of 1675-1725 (Owsley et al., 1982).
In addition to grave goods, multivariate analysis of cranial measurements supported the archaeological internal chronology (Owsley et al., 1982). Using crania from the Mobridge Site, Owsley et al. (1982) utilized stepwise discriminant analysis to test for heterogeneity between the three features. In addition, they wanted to compare the Mobridge samples to the earlier Rygh Site, the intermediate Buffalo Pasture Site and the later Leavenworth Site in order to see where the morphology of the cemetery samples from the different features would cluster (Owsley et al., 1982). In this way, they hoped to assign a chronology based on skeletal morphology. They discovered that the skeletal samples from Mobridge Features 1 and 3 align more closely with prehistoric Rygh, while Feature 2 fell between the intermediate Buffalo Pasture site and the later historic Leavenworth Site, thus supporting the archaeological chronology (Owsley et al., 1982).

Larson

The Larson Site cemetery, denoted with the trinomial of 39WW2, is located in Walworth County, South Dakota just outside of the Larson Site village on the east bank of the Missouri River. The village was occupied for a relatively short period of about 35 years during the Post-Contact Coalescent Tradition from approximately 1750 – 1785 (Owsley and Bass, 1979). Many of the burials contained goods of European origin (Perzigian, 1975). The collection derived from the site is considered one of the largest available from a single site in the Northern Plains area (Owsley and Bass, 1979). The entire cemetery sample is composed of 628 individuals and contains male and female individuals of all ages (Owsley and Bass, 1979).

Like Leavenworth, Larson was excavated by the University of Kansas under the direction of Dr. William M. Bass. The construction of the Oahe reservoir system, which flooded several sites, including Larson, necessitated their salvage. Owsley and Bass (1979) reported that during excavation of the cemetery, the water level gradually rose, which endangered the burial area and
washed out some skeletons. They felt that the loss of skeletal material was minor, estimating that 90% of the skeletons were unaffected.

Sociohistorically, the Arikara of the Larson Site are considered to be a sedentary tribe, who lived in earth lodges and practiced intensive horticulture. Their primary crop was corn (Perzigian, 1975). There is a possible cultural filter created by seasonal hunting expeditions (Owsley and Bass, 1979). The hunting parties consisted of healthy members of the population, while the old, sick and incapacitated stayed behind to guard the fields (Hurt, 1969). Members who died away from the village may not have been interred in the village cemetery (Owsley and Bass, 1979).

The Arikara of the Larson site customarily buried individuals in single, primary inhumations (O’Shea, 1981). Interment consisted of a flexed posture, oriented in a northwesterly direction and covered by a wooden burial covering. O’Shea’s (1981) analysis of social configurations and mortuary practices revealed three levels of elaboration in the mortuary practices of the Larson Site Arikara. The first level contained only males, who were buried with large quantities of artifacts, including tools and rare materials (O’Shea, 1981). The second level was composed of males buried with fewer artifacts as well as a smaller number of adult females and sub-adults, who were buried with a large quantity of Olivella shell beads (O’Shea, 1981). The third level contained the majority of the population, who were buried with very few artifacts, mostly ornamentation, though a few native made tools were also discovered with them (O’Shea, 1981).

Demographic analysis revealed an extraordinarily high number of deaths occurring within the first year of life (Owsley and Bass, 1979). When compared to several world and American Indian populations, life expectancy for the Larson population was the lowest; the greatest contributing factor was the high infant death rate (Owsley and Bass, 1979). Compared to the Leavenworth or Sully Arikara skeletal populations, Larson had the highest number of deaths annually (Owsley and Bass, 1979).
The cause of death is normally unknown, but there is some evidence of the diseases that affected the Larson Site Arikara. One area of the cemetery was filled with a larger number of multiple inhumations and an even higher percentage of subadults. This change in dimensions is possibly an indication of a smallpox epidemic which was recorded in 1780-1781 during the Arikara occupation of the Larson Site (Owsley and Bass, 1979). There are also individuals affected by skeletal tuberculosis, and evidence of intertribal warfare (Owsley and Bass, 1979).

Leavenworth

The Leavenworth Site cemetery, denoted with the trinomial 39C09, was occupied during the last Coalescent Variant, the Disorganized (Gilbert and Bass, 1967). It is located in present day Carson County, South Dakota, not far from Mobridge. The cemetery is situated on rugged hills overlooking a terrace where the remains of two villages were found. The Arikara inhabited Leavenworth site for about 30 years from approximately 1802-1832. Lewis and Clark visited them in 1804 (Gilbert and Bass, 1967). In 1832, Col. Leavenworth shelled the village ending the Arikara occupation (Gilbert and Bass, 1967).

Dr. William M Bass directed the excavation of the Leavenworth Cemetery with the Anthropology Department of the University of Kansas (Gilbert and Bass, 1967). This multi-component cemetery consisted of five areas denoted as A, B, C, D, and E (Byrd and Jantz, 1994). From these five areas, 278 burials were excavated (Gilbert and Bass, 1967).

The Arikara of the Leavenworth Village typically buried their dead in a single primary inhumation placing them in a flexed posture (O’Shea, 1981). Unlike the earlier Larson Site Arikara, there is no normative direction in which the dead were laid to rest (O’Shea, 1981). Wooden burial coverings, however, were bestowed upon each individual burial (O’Shea, 1981).
A large number of bison robe fragments were also found among the burials possibly indicating that individuals were buried in them (O’Shea, 1981).

O’Shea’s (1981) analysis of mortuary treatment did not distinguish any clear ranks among the dead buried there. He did discover that some were buried with more grave goods than others, but he did not find a pattern to the artifacts or to the individuals that would indicate a social distinction (O’Shea, 1981). The Arikara of Leavenworth village buried males and females of all ages with a larger number of grave goods. Those interred with less grave goods tended to have mixed sets of trade ornaments and fewer objects of ritual significance (O’Shea, 1981).

Ethnohistorically, Leavenworth Village was occupied by an accumulation of survivors from Arikara villages decimated by disease, starvation, and Sioux attack. The different burial areas are thought to reflect different bands, possibly from former associations in their home villages (O’Shea, 1981).

Two studies, one by Key and Jantz (1990), and the other by Byrd and Jantz (1994) examined the physical heterogeneity of the Leavenworth Cemetery. Key and Jantz (1990) first assessed the degree of cranial variability of the skeletal samples available from the Leavenworth Cemetery. This variability was then compared to the variability of a sample from the archaeological Bad-River phase, and the Larson cemetery sample. Larson was chosen as a baseline because it is a large well-documented single-occupation site with homogeneous mortuary practices (Key and Jantz, 1990; O’Shea, 1981). Key and Jantz’s (1990) results demonstrated the high degree of variability among the individuals buried in the Leavenworth cemetery. Leavenworth’s variability was greater than the archaeologically assembled Bad River Phase and much greater than the more homogeneous Larson site (Key and Jantz, 1990).

While Key and Jantz (1990) had demonstrated the heterogeneity of the site, the rationale for each burial was not understood until Byrd and Jantz (1994) examined the distinct burial areas.
They hypothesized that different geographic phases were represented by the individuals buried in Leavenworth Cemetery (Byrd and Jantz, 1994). Ethnohistorically, it was reported that Leavenworth was settled by Arikara groups from the nearby Grand-Moreau region and from the southern Bad-Cheyenne region (Abel, 1939). Archaeologically, pottery from two phases, the Le Beau “Left Bank” Phase and the Bad River “Right Bank” Phase are found in the Leavenworth Village and cemetery (Byrd and Jantz, 1994). Using stepwise discriminant analysis, the researchers compared the craniometric data from the Leavenworth burial areas to those from known Le Beau and Bad River samples (Byrd and Jantz, 1994). Their results demonstrated that a majority of the individuals interred in the Leavenworth cemetery were classified as coming from the Bad River and the Le Beau phases, with a majority classifying within the Le Beau phase (Byrd and Jantz, 1994).

Comparative Health Studies

In 1984, Jantz and Owsley analyzed the remains from seven Arikara skeletal samples. Included in these seven sites were the Leavenworth Site, the Larson Site and Mobridge 1 and 2 (Jantz and Owsley, 1984). Jantz and Owsley (1984) examined the differences in long bone growth from sites in the Extended Coalescent, the Post-Contact Coalescent, and the Disorganized Coalescent. It was hypothesized that populations from the Extended Coalescent would display moderate environmental stress because of adaption to village farming (Jantz and Owsley, 1984). The Post-Contact Coalescent was hypothesized to be marked by an increase in health because of the introduction of horses to assist with farming and the end of a cool, dry environmental episode. The authors describe the Disorganized Coalescent as a time of extensive environmental stress, epidemic disease and social disorder (Jantz and Owsley, 1984). A healthy population should have better growth (be taller) than those of comparative age from an unhealthy population (Saunders,
2000). While the Post-Contact Coalescent was the time period that displayed the best health, it was the Extended Coalescent, not the Disorganized that had the lowest health indicators.

Table 1 shows the results of Jantz and Owsley’s (1984) study. The Post-Contact Coalescent had the highest growth rate; the Disorganized Coalescent had the lowest growth rate, and populations from the Extended Coalescent fell somewhere in the middle (Jantz and Owsley, 1984).

<table>
<thead>
<tr>
<th>Coalescent</th>
<th>Site</th>
<th>Health</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extended</td>
<td>Mobridge 1</td>
<td>Lowest</td>
</tr>
<tr>
<td>Post-contact</td>
<td>Larson, Mobridge 2</td>
<td>Highest</td>
</tr>
<tr>
<td>Disorganized</td>
<td>Leavenworth</td>
<td>middling</td>
</tr>
</tbody>
</table>

Using the same populations as their 1984 article, Owsley and Jantz (1985) analyzed the growth of fetal and perinatal remains. Smaller remains were assumed to be premature and reflective of fetal underdevelopment caused by maternal environmental stress (Owsley and Jantz, 1985). Rather than utilize the coalescent variants as cut-off points, Owsley and Jantz (1985) divided the skeletal samples into an earlier and a later period. Using longbone lengths, the researchers discovered that the mode age assignment for perinatal skeletons in the earlier sites was 39 weeks, while the mode for the later site was 38 weeks (Owsley and Jantz, 1985). In addition, the later sites contained a greater percentage of skeletons falling in the 34 to 38 week categories (Owsley and Jantz, 1985).

Table 2 displays the results of Owsley and Jantz’s 1985 study. Late group cemeteries revealed a higher percentage of smaller than normal perinatal remains, leading the researchers to conclude that a poorer maternal environment existed during the later time periods, indicative of greater environmental stress (Owsley and Jantz 1985).
<table>
<thead>
<tr>
<th>Time Period</th>
<th>Site</th>
<th>Perinatal Health</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early</td>
<td>Larson, Mobridge</td>
<td>Higher</td>
</tr>
<tr>
<td>Late</td>
<td>Leavenworth</td>
<td>Lower</td>
</tr>
</tbody>
</table>
Chapter 4
PROJECT SPECIFICATIONS

Asymmetry in human skeletal measures may be a result of genetic robusticity, evolutionary genetics, environmental or socio-historic stress, behavioral disorders, handedness, as well as biomechanical loading and is represented as either directional or fluctuating asymmetry (Albert and Green, 1999; DeLeon, 2007; Harris and Nweeia, 1980; Hershkovitz et al., 1993; Kieser et al., 1997; Kohn and Bennett, 1986; Rhodes and Knüsel, 2005; Ruff and Jones, 1981).

Fluctuating asymmetry has been tested as a tool in the bioarchaeological analyses of status, health, and genetic robusticity (Albert and Green, 1999; DeLeon, 2007; Hummert and Van Gerven, 1983; Kohn and Bennett, 1986). It can detect disruptions in the development of individuals caused by environmental stress (Little et al., 2002; Kieser et al., 1997; Mooney et al., 1985; Schell, 1981). Previous studies have shown the usefulness of fluctuating asymmetry as an indicator of the level of environmental stress encountered by an individual as they were growing (Albert and Green, 1999, DeLeon, 2007; Kieser et al. 1997; Kohn and Bennett, 1986; Little et al. 2002; Mooney et al., 1985; Schell, 1981). The analysis of environmental stressors in individual development informs an understanding of the effects of stress in populations (Albert and Green, 1999). Degrees of environmental stress can then be compared with other populations, placing the health of the population into context (Albert and Green, 1999). This information adds to our understanding of past populations and the relationship with their environment.

This study conducts research similar to that done by Albert and Green (1999) in Sudanese Nubia, where two historically and genetically related populations, one with stronger recorded environmental stress, were analyzed for comparative degrees of fluctuating asymmetry in epiphyseal fusion. Albert and Green (1999) sought to discover if the more stressed Early Christian population displayed higher degrees of fluctuating asymmetry than the less stressed
Late Christians. Their results supported prior research on the Christian Nubians (Albert and Green, 1999).

Using the collections of Arikara housed at the University of Tennessee, Knoxville, Jantz and Owsley (1984), and Owsley and Jantz (1985) compared the health profile of different time periods among the Arikara and reported significant differences in health between the temporally organized villages. This thesis utilizes these same Arikara collections in an effort to test the sensitivity of stages of epiphyseal union to fluctuating asymmetry, as a measure of environmental stress, following the standards set by Albert and Green (1999). Bilateral stages of epiphyseal union in juveniles from three temporally distinct Arikara village cemeteries; Mobridge, Larson and Leavenworth are compared. This study tests the usefulness of this visual method of evaluation to identify the degree of environmental stress expressed as FA.
Chapter 5

MATERIALS AND METHODS

Materials

Using the collections of Arikara housed at the University of Tennessee, Knoxville this study examined fluctuating asymmetry of matched bilateral epiphyseal unions in individuals from the Mobridge, Larson and Leavenworth Village cemeteries. Understanding the sensitive nature of utilizing Native American human remains within a scientific study, all skeletal collections used complied with federal laws pertaining to human remains such as NAGPRA and were treated respectfully.

The University of Tennessee, Knoxville’s collection contains several cemetery samples composed of approximately 500 individuals from fetal to 12 years old (Saunders, 2000). The Arikara cemetery samples, originating from the Middle Missouri subarea, range in date from 1600 to 1832 A.D.. The Mobridge, Larson and Leavenworth cemetery populations were ideal for this study in that: 1) environmental stress had been previously demonstrated (Abel, 1939; Blakeslee, 1994; Byrd and Jantz, 1994; Jantz and Owsley, 1984; Merchant, 1973; Merchant and Ubelaker, 1977; Owsley and Bass, 1979; Owsley and Jantz, 1985; Ramenofsky, 1987; Rogers, 1990; Trimble, 1994) and 2) there were numerous well-preserved, nearly complete skeletons ranging from young adolescent to young adulthood (Jantz and Owsley, 1984; Owsley and Bass, 1979; Owsley and Jantz, 1985).

Age and sex of individuals was established using standardized methods (Jantz and Owsley, 1984; Owsley and Bass, 1979; Owsley and Jantz, 1985). Previous researchers based their sex assessments on pelvic and cranial morphology, as well as cranial and dental metric multivariate analysis using standards set by Bass (1972), Krogman (1962), Lyon (1970), Owsley (1975),
Phenice (1969) and Stewart (1968). Sex was not examined for subadults under the age of nine (Owsley and Bass, 1979).

Adult ages were estimated based on stages of pubic symphysis morphology developed by Gilbert and McKern (1973), and McKern and Stewart (1957). Subadults were aged using dental calcification standards developed by Moorees et al. (1963) and Merchant (1973). The greatest weight was given to evaluation of age based on epiphyseal closure from McKern and Stewart’s (1957) standards (Owsley and Bass, 1979).

A total of 170 individuals, from developmental ages 11-30 years comprised the sample. There were 41 individuals from the Leavenworth cemetery, 96 individuals from the Larson cemetery, and 35 individuals from the Mobridge cemetery (Fig. 1).

Figure 1. Arikara sample sizes N = 170

All sites include individuals of both sexes as well as individuals whose sex was not identifiable based on the standards used (Fig. 2). The Leavenworth sample from the Disorganized Coalescent Variant, consisted of 10 males, 15 females, and 16 individuals of unknown sex. The largest sample, from the Post-Contact Larson site, consisted of 28 males, 45 females, and 23
individuals of unknown sex. The earliest sample from the Mobridge Site, both Mobridge 1 & 2, contained 4 males, 9 females, and 22 of unidentifiable sex.

Figure 2. Sex - Larson, Leavenworth and Mobridge  N = 170

Even though most epiphyses are completely fused by age 18-22, this sample included individuals from 11 to 30 in order to include fusion of the medial clavicle and to account for the possibility of premature or delayed skeletal growth and maturation. As seen in Figure 3 all three sites contained individuals from each age group. Age ranges were derived from the developmental stages already indentified by previous researchers.
Individuals of unknown sex were most likely younger children who do not display the characteristics needed to identify sex (Saunders, 2000). This bioarchaeological pattern created by the lack of sex hormones in subadults is borne out in this sample in Figure 4. In all three cemetery samples, the individuals whose sex was too difficult to determine mostly within the younger subadults.
Figure 4 – Age of individuals with unknown sex N = 61
Methods

The data collection and analysis followed the standard set by Albert and Green (1999). The stages of epiphyseal union were assessed for paired elements including the proximal humerus, as well as the medial and lateral epicondyles of the distal humerus, the proximal and distal epiphyses of the humerus, the radius, the ulna, femur, tibia, and fibula; the anterior iliac crests and ischial tuberosities of the os coxae and the medial clavicular epiphyses. In total, 18 paired epiphyseal fusion sites were scored.

The progression of epiphyseal fusion was scored in four stages (Table 3). A score of 0 represents no union (with or without the separate epiphysis); 1 represents an epiphysis where less than half is fused to the diaphysis; 2 represents a nearly complete or recent union (from greater than half fused to a complete fusion where the line of fusion is still clear); and a score of 3 represents a complete union where only a scar may remain (Albert and Green, 1999; McKern and Stewart, 1957). All data were recorded and computed using Microsoft Office Excel 2003.

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>no union</td>
</tr>
<tr>
<td>1</td>
<td>&lt;1/2 fused</td>
</tr>
<tr>
<td>2</td>
<td>&gt;1/2 fused, but not complete</td>
</tr>
<tr>
<td>3</td>
<td>fusion complete, a scar may remain</td>
</tr>
</tbody>
</table>

Using the University of Tennessee, Knoxville, collection individuals 11-30 years of age whose remains contained matching epiphyseal endings were scored. Asymmetrical individuals were reexamined to protect against recording error. In order to identify asymmetric individuals and to compare degrees of asymmetry between cemetery populations, the mean of all left side scores
and the mean of all right side scores were computed for each individual. The left mean score
minus the right mean score indicated which individuals were asymmetrical and which direction
the asymmetry favored. If the left side is more advanced than the right side, then the result of
subtracting the right mean from the left mean (L-R) is a positive number, if however the right side
is more advanced, then the results will be negative. Thus each individual had three scores, a left
side mean, a right side mean, and a L-R directional score. A paired sample t-test was then
computed by site to see if the differences between mean left side and mean right side were
statistically significant and to see if the differences deviated significantly from random chance.
RESULTS

Out of a total sample of 172, nine individuals were found to display some asymmetry. There were three asymmetrical individuals from the Larson Site, three from Leavenworth and three from Mobridge Site (Fig. 5).

Figure 5. Asymmetric individuals by site N = 9

Asymmetric individuals were identified from both sexes, three males, and three females, while three were of unknown sex (Fig. 6).

Asymmetric individuals fell within two primary age groups, six were within the 18-30 age group, two were aged 13-17 years and one was aged as a child (Fig. 7). It is interesting to note that most of the asymmetries fell within an age range when most epiphyses have completed their closure (Saunders, 2000).
Asymmetries were found in eleven skeletal sites: medial humerus, the lateral epicondyles of the humerus, the distal radius, the distal ulna, the proximal femur, proximal tibia, the distal tibia, proximal fibula, the distal fibula, the medial clavicle, and the anterior iliac crest. The only sites found to be asymmetrical in more than one individual was the proximal fibula and the distal fibula (Table 4). In general the direction of the asymmetries favored the right as being more advanced than the left side, though the lateral epicondyles of the humerus, the proximal end of the tibia, the distal fibula, and the anterior iliac crest, favored the left side (Table 4).
Table 4. Location of Asymmetric Epiphyses

<table>
<thead>
<tr>
<th>Location of asymmetries</th>
<th># of asymmetries</th>
<th>Direction of asymmetries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medial humerus</td>
<td>1</td>
<td>R&gt;L</td>
</tr>
<tr>
<td>Lateral epicondyles of Humerus</td>
<td>1</td>
<td>L&gt;R</td>
</tr>
<tr>
<td>Distal Radius</td>
<td>1</td>
<td>R&gt;L</td>
</tr>
<tr>
<td>Distal Ulna</td>
<td>1</td>
<td>R&gt;L</td>
</tr>
<tr>
<td>Proximal Femur</td>
<td>1</td>
<td>R&gt;L</td>
</tr>
<tr>
<td>Proximal Tibia</td>
<td>1</td>
<td>L&gt;R</td>
</tr>
<tr>
<td>Distal Tibia</td>
<td>1</td>
<td>R&gt;L</td>
</tr>
<tr>
<td>Proximal Fibula</td>
<td>2</td>
<td>R&gt;L</td>
</tr>
<tr>
<td>Distal Fibula</td>
<td>2</td>
<td>R&gt;L and L&gt;R</td>
</tr>
<tr>
<td>Medial Clavical</td>
<td>1</td>
<td>R&gt;L</td>
</tr>
<tr>
<td>Anterior Illiac Crest</td>
<td>1</td>
<td>L&gt;R</td>
</tr>
</tbody>
</table>
Of the nine asymmetrical individuals within the Larson, Leavenworth or Mobridge sites six displayed only 1 asymmetry, two displayed 2 asymmetries and only one individual displayed 3 asymmetries (Fig 8).

Figure 8. Number of asymmetries per individual \( N = 9 \)

In this study, of 172 individuals, skeletal maturation was more advanced on the left side for four skeletal locations, one from Larson and two from Leavenworth, and one from Mobridge. In nine epiphyses the right side was more advanced than the left side, three cases from Larson, three cases from Leavenworth and three cases from Mobridge (Fig. 9).
The results of the paired sample t-tests for each population showed no statistically significant asymmetry (Table 5). The incidences of asymmetry which occurred in the populations were not enough to deviate significantly from 0, at $\alpha = 0.05$. The null hypothesis was stated as: $H_0: \mu = 0$, with the alternative hypothesis stated as: $H_1: \mu \neq 0$.

Table 5. Results of Paired Sample T-test

<table>
<thead>
<tr>
<th>Site</th>
<th>N</th>
<th>t-score needed for significant difference</th>
<th>t-score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leavenworth</td>
<td>41</td>
<td>&gt;1.68</td>
<td>1.00</td>
</tr>
<tr>
<td>Larson</td>
<td>96</td>
<td>&gt;1.98</td>
<td>0.37</td>
</tr>
<tr>
<td>Mobridge</td>
<td>35</td>
<td>&gt;2.02</td>
<td>1.29</td>
</tr>
</tbody>
</table>

Leavenworth with an N of 41 and a DF of 40 would have needed a t-score greater than 1.684 to be statistically significant. Leavenworth’s data created a t-score of 1.00, which is too small for acceptance of the alternative hypothesis (Table 5).
Larson site with an N of 96 and a DF of 95 would have needed a t-score of 1.98 to be considered statistically significant. Larson’s data created a t-score of 0.37, which is too small for acceptance of the alternative hypothesis (Table 5).

Mobridge site with an N of 35 and a DF of 34 would have needed a t-score greater than 2.021 to be considered statistically significant. Mobridge’s data created a t-score of 1.29, which is too small for acceptance of the alternative hypothesis (Table 5).

All three sites failed to reject the null hypothesis of deviation from symmetry.
Chapter 7

DISCUSSION AND CONCLUSION

The method of evaluating environmental stress based on statistically significant differences in degrees of asymmetrical epiphyseal fusion failed to detect any differences among three Arikaran tribes from three different time periods. Why did this method, which supported historical data in Albert and Green’s 1999 study and was further supported by other asymmetry studies (DeLeon, 2007), fail to detect environmental disruptions in this Native American population?

Albert and Green’s (1999) study found statistically significant deviations from symmetry in their total sample of 90 individuals. Of those 90 there were 64 cases of asymmetry; 71% of individuals displayed some asymmetry (Fig. 9). In my total sample of 172 individuals with 34 locations evaluated for each individual, only 9 individuals, or 5%, displayed any asymmetry in the fusion of their epiphyses (Fig. 10).

![Figure 9. Albert and Green’s (1999) percent of asymmetrical Nubians N = 90](image_url)
Figure 10. Percent of asymmetric New World Arikara N = 170

Why would there be such a large degree of difference between these two environmentally stressed populations? One possibility is that the Christian Nubians of the Old World were under more environmental stress than the Arikara Native American populations of the New World. This possibility is not supported by historical data which displays a preponderance of examples of severe environmental stress in the Arikara (Abel, 1939; Blackslee, 1994; Byrd and Jantz, 1994; Jantz and Owsley, 1984; Merchant, 1973; Merchant and Ubelaker, 1977; Owsley and Bass, 1979; Owsley and Jantz 1985; Ramenofsky, 1987; Rogers, 1990; Trimble, 1994). The Arikara were hit with multiple small pox and other disease epidemics, including measles and cholera (Rogers, 1990). While death from small pox and other epidemic disease may have been too quick to illicit a skeletal response, survivors would have been left with a broken tribe (Calloway, 1999; Rogers, 1990). Parents would be unable to feed their children; hunting would have been frozen until enough people were well enough to continue. Starvation was not unusual and was the secondary cause of death during a pandemic (Calloway, 1999). The fact that their population steadily fell
from a prehistoric level of an estimated 9000, to 380 in the year 1904 indicates rather high
degrees of environmental stress (Rogers, 1990). However, in this sample it was not reflected in
uneven skeletal development.

In addition, environmental stress had already been displayed and compared within the Arikara
sample. Based on Jantz and Owsley’s studies (1984, 1985), environmental stress had been
displayed by these same individuals and compared, based on long bone length and percentage of
early term and perinatal skeletons.

It is possible that asymmetry of epiphyseal fusion is under genetic control and is a part of our
catalogue of human variations. Waddington’s (1942, 1953) fruit fly experiments showed that the
threshold level for environmental disruption of development varies. Extending this insight to the
Arikara of North America, it is possible that the Arikara are more canalized than Nubian North
Africans; the effects of environmental disruption on skeletal development may be corrected faster
among the Arikara.

If FA in epiphyseal union does reflect environmental stress, it is possible that the Arikara
populations display strong canalization of their growth and development. The difference in the
occurrence of asymmetry in epiphyseal union from one continent to another, displays a
population level difference in a biological response to stress. Different populations might vary in
their threshold level for canalization resulting in differential affects of environmental stress on
skeletal growth and development.

Another possibility is that the levels of asymmetry are the result of inbreeding. Considering
the findings of higher FA amongst inbred populations, it is possible that the asymmetrical
epiphyseal fusion is a reflection of higher degrees of inbreeding (Schaefer at al., 2006). The data
would then be showing that the Christian Nubians were more inbred or had higher levels of
homozygosity, perhaps leading to lower environmental thresholds. The Arikara may have high
degrees of heterozygosity as a result of population movement, warefare, and mass tribal relocation.

This is not the first time that the data did not perform as expected. Little et al. (2002) found higher levels of asymmetry among White middle class Texans than among the lower socio-economic Native Mexican school children. Despite the environmental advantages of the middle class Texan lifestyle and the inbreeding and environmental stress among the Mexican school children, it was the descendants of Europeans who displayed higher than expected FA, while the descendants of New World Native Americans displayed lower than expected FA (Little et al., 2002).

Albert and Green’s (1999) results may be explained by the Baer and Durkatz (1957) study, which found that the same bilateral trait can show variation in timing. Baer and Durkatz (1957) however, found more variation in osseus centers than in epiphyses.

This research found that evaluation of FA in the epiphyseal union was not a useful method for comparing environmental stress among the Arikara of North America. The lack of FA in Arikara epiphyseal union may be another trait of genetic variation, the result of a higher threshold to environmental disturbances, or from stronger developmental canalization.
Further Research Suggestions

Albert and Green’s research on FA of epiphyseal union was supported by their analysis of FA from the cranial remains, as well as earlier evaluation of the same population’s longbone growth (Deleon, 2007; Hummert and Van Gerven, 1983). A logical next step would be to test the Arikara crania for comparable FA.

Another avenue for additional research would be to see if the higher threshold for canalization holds for other Native American groups. Additional studies of FA in epiphyseal fusion among other Native American groups would allow us to see if the pattern is geographical or perhaps varies within the North American populations.
### APPENDIX A
Asymmetric Individuals

<table>
<thead>
<tr>
<th>NAGPRA cat #</th>
<th>Site</th>
<th>State</th>
<th>County</th>
<th>feature no</th>
<th>burial no.</th>
<th>age</th>
<th>sex</th>
</tr>
</thead>
<tbody>
<tr>
<td>62</td>
<td>Larson 39WW2</td>
<td>South Dakota</td>
<td>Walworth</td>
<td>F201</td>
<td>12h</td>
<td>13-17</td>
<td>?</td>
</tr>
<tr>
<td>134</td>
<td>Larson 39WW2</td>
<td>South Dakota</td>
<td>Walworth</td>
<td>F201</td>
<td>111c</td>
<td>18-20</td>
<td>F</td>
</tr>
<tr>
<td>168</td>
<td>Larson 39WW2</td>
<td>South Dakota</td>
<td>Walworth</td>
<td>F201</td>
<td>71b</td>
<td>18-30</td>
<td>M</td>
</tr>
<tr>
<td>587</td>
<td>Leavenwoth39CO9</td>
<td>South Dakota</td>
<td>Corson</td>
<td>F202</td>
<td>8a</td>
<td>13-17</td>
<td>?</td>
</tr>
<tr>
<td>584</td>
<td>Leavenwoth39CO9</td>
<td>South Dakota</td>
<td>Corson</td>
<td>F220</td>
<td>B7</td>
<td>18-30</td>
<td>F</td>
</tr>
<tr>
<td>530</td>
<td>Leavenwoth39CO9</td>
<td>South Dakota</td>
<td>Corson</td>
<td>F201</td>
<td>B15</td>
<td>18-30</td>
<td>M</td>
</tr>
<tr>
<td>370</td>
<td>Mobridge39WW1</td>
<td>South Dakota</td>
<td>Walworth</td>
<td>F302</td>
<td>21d</td>
<td>~20</td>
<td>F</td>
</tr>
<tr>
<td>366</td>
<td>Mobridge39WW1</td>
<td>South Dakota</td>
<td>Walworth</td>
<td>F302</td>
<td>B18</td>
<td>~19</td>
<td>M</td>
</tr>
<tr>
<td>328</td>
<td>Mobridge39WW1</td>
<td>South Dakota</td>
<td>Walworth</td>
<td>F303</td>
<td>1e</td>
<td>child</td>
<td>?</td>
</tr>
</tbody>
</table>

N = 9
LITERATURE CITED

Abel AH. 1939. Tabeau’s narrative of Loisel’s expedition to the Upper Missouri. Norman; University of Oklahoma press.


Giraud M. 1953. Histoire de la Louisiane Francaise, 1698-1715. Paris; University of France


Murray SA, and Gridley T. 2006. Snail family genes are required for left-right asymmetry determination, but not neural crest formation, in mice. Proc Natl Acad Sci 103(27)10300-10304.


