Urbanisation and its impact on the human skeleton:

Researching the bone morphological differences between Middenbeemster and Zwolle.

Author: Sebastiaan Reinders.

Cover picture: accessed on 12-06-2018

https://i.pinimg.com/originals/d4/3a/59/d43a5967b471628587bd35a44c3bbd55.jpg

Urbanisation and its impact on the human skeleton:

Researching the bone morphological differences between Middenbeemster and Zwolle.

Name: Sebastiaan Reinders, s1410709

Course: BA3-Thesis tutorial, (1043SCR1Y-17-18ARCH)

Name supervisor: Dr. R. Schats

Specialisation: Osteoarchaeology

University of Leiden, Faculty of Archaeology

Leiden, 12-06-2018. Final version.

Table of contents:

1. Introduction:

This research aims to study the differences in activity patterns as reflected by bone morphology of the lower limbs from the human skeleton between a rural population and urban population within the Netherlands. Julius Wolff, a nineteenth century German anatomist, was one of the first to note the great ability of bone to respond to mechanical loading by altering its size and shape. This concept, later termed Wolff's law, is currently commonly used to study the activity patterns during life (Larsen 1997; Ruff et al. 2006; Schats 2016, 42). Activity reconstruction within archaeological context can obtain valuable information about the individuals themselves and as a result about the populations in which they were part of as well. Using bone morphology to research mechanical loading and mobility between these two populations, makes it possible to study differences in of activity between rural and urban communities in the Post Medieval period.

1.1 Research problem:

When researching difference between rural and urban areas, the first thing people tend to think about is the differences in profession/labour and environment. It is unclear however how much said differences within the socioeconomic environments from both rural and urban areas influence the mechanical and physical loading of the human body as shown within the bone morphological changes. Especially since the high urbanisation level within the Netherlands makes the difference between rural and urban less apparent, which means that the question "what is considered rural and what is considered urban" will be harder to answer. It is possible to say some professions/activities are specifically urban or rural but the problem however is that it is usually not possible to reconstruct specific habitual activities by studying bone morphology alone. This is mainly because it is not yet known for sure in which manner the differences in activity can result in changes in bone morphology and how the human body is strained by said activities. This statement indicates that it is simply not possible to tell what specific occupation an individual had before their death, but when again referring to "Wolff's law" (Ruff et al. 2006, 484), a difference in bone morphology in the lower limbs between the rural and urban populations could still be present.

1.2 Research questions:

Considering the research problem and goal, the research question is as follows: What are the differences in activity patterns as reflected in the lower limbs morphology between a collection of urban individuals from the city of Zwolle and the rural individuals of the Middenbeemster, and can these be related to the socio-economic environment?

The sub questions that will be discussed are about differences between the men and women, between and within both post medieval populations to study the influence of differences in environments. This is to research the differences between both sexes separately between the rural and urban environment, as well as studying possible changes between men and women within the same socioeconomic environment to say something about sexual differences in labour, resulting in three sub questions:

1. What are the differences in activity between males and females both within the two populations?
2. What are the differences in activity between the females of both populations?
3. What are the differences in activity between the males of both populations?

1.3 Approach:

To answer these research questions, two skeletal collections, one from a rural context and one from an urban context, will be compared to each other. The two collections that will represent the rural and urban populations originate from Middenbeemster, which is a rural farming village, and Zwolle, which is an urban city with official city rights. Both collections originate from cemeteries dated from the post medieval time periods.

- The Middenbeemster collection consist of burials from the cemetery of the Keyserkerk, from which the majority dates from 1829 AD to 1866 AD and these also happen to be the most recent burials that originate from this excavation(Lemmers et. al. 2013, 35).
- The Zwolle collection consists of burials from within the Broerenkerk, which is a church. This collection dates from 1681 A.D. to 1828 A.D. which is a wider time period but still post medieval. The sample collection used dates mostly from the 19^{th} century which correlates better with the Middenbeemster size date wise.

> These burials are from within the church which means the population can be considered middle to high class in the society (Clevis and Constandse-Westerman 1992).

Within these collections, the research will be focused on the lower limb bone morphology, as stated in the research question. To provide comparable data two indices will be analysed. These indices are the platymeric index and the platycnemic index which both show the flatness of the lower limb bones within their diaphyseal shapes. The indexes are both found on the top parts of the femur (platymeric) and the tibia (platycnemic). The amount of flatness indicates loading and mobility differences, with more flatness meaning more physical strain and therefor more mechanical loading/mobility. These indices have been measured already and thus are already provided for the study in question. The platymeric index is to be found on the proximal part of the femur and measures the diaphyseal shape of the femur and the platycnemic index is found on the proximal end of the tibia near the nutrient foramen, which measures the diaphyseal shape of the tibia.

The results of these measurements will be compared to each other between populations, between the female and male sexes and between the left and the right lower limbs to make sure that all possible differences are covered. Anomalies and other points of interests will be studied as well and when possible compared between the two collections. The results will be tested for statistical significance and will be discussed accordingly.

In short the: the activity patterns that are present will not tell us exactly who are what occupied the individual’s life, but it will show differences between the different lifestyles of rural and urban areas which in turn can be connected to certain aspects within these lifestyles. Therefore the aim of this study is to highlight these differences by using bone morphology combined with activity reconstruction to better understand the differences between rural and urban populations within the Netherlands, when only concerning the human skeletal remains from said populations.

1.4 Thesis structure:

The thesis will consist of six chapters. Chapter two will discuss the theoretical framework which consists of the current state of affairs about activity reconstruction within archaeology and bone morphology. Chapter three elaborates upon materials that will be used to acquire the data. Chapter four discusses the methods used. Chapter five will show the results including the statistical analysis and the comparisons that have been done. Chapter six will discuss the results within the context of this research and chapter seven will answer the research questions, whilst also referring to possible future research which should or can be done around this subject.

2. Theoretical framework:

To better understand what the differences between rural and urban are when comparing bone morphological differences, it is first necessary to understand which indices are to be studied and how bone morphological research can help answer the main research question. To accomplish this multiple researches have been studied as examples of how bone morphological differences can reconstruct the activities of past populations.

2.1 Activity reconstruction:

Since this research concerns two separate populations which have a different socioeconomic context, archaeological activity reconstruction will play a part in the study of the differences between rural and urban areas within the Netherlands. When considering the fact that "Wolff's law" states that bone adapts to the user (Ruff et al. 2006), it is safe to assume that the environment in which these users or individuals perform physical labour does influence the bone morphology or adaptation, since the user adapts to said environment but only when the activities differ. This adaptation to the environment means that the human skeleton has to adapt as well to fulfil different functional demands, which will be possibly visible in the indices that are analysed within this research. The concept of functional adaption has been used in several studies for both the upper and lower limbs (Schats 2016, 45). In this research only the lower limbs are analysed. The bone morphology of the lower limbs will be compared between the left and the right limbs, between the female and male sexes and between the rural and urban populations. Several biomechanical studies have demonstrated that size, shape and thickness of long bone shafts are related to the mechanical loading that is placed on the bone (Schats 2016, 74). To research these activity differences in the lower limbs the study focusses, more specifically, on the proximal flatness of the femur which is the platymeric index and the flatness of the tibia at the nutrient foramen which is the platycnemic index. Both these indexes have proven to be valuable for reconstructing mobility patterns in archaeological populations (bridges et al. 2000; Pomeroy and Zakrzewski 2009).

As an example of successful use of activity reconstruction, Bridges *et al.* link activity levels with specific subsistence economies within the different cultural groups from west-central Illinois (Bridges et al. 2000, 218). Essentially they link the radical change in diaphyseal strength, which declines in the humerus of both female and male individuals both because of different reasons, to the introduction of maize cultivation and the differences in activities these new dietary changes bring (Bridges et al. 2000). Some of the reasons mentioned in the study from Bridges *et al.* are that the use from atlatl's changed to bows at first which resulted in minor differences in male bone morphology, and after the use of maize intensifies the female humeral strength declined because maize is possibly easier to cultivate than native small seeds (Bridges et al. 2000, 232-233, 236). It is also important to note that bone size and shape can also be influenced by several non-mechanical influences such as age-related changes, nutrition, and pathological conditions. Despite this the study of long bone morphology or shape has proved to be particularly valuable in osteoarchaeology for reconstructing past activities (Schats 2016, 44).

Another example of archaeological activity reconstruction using bone morphological changes, Palmer et al. analyze osteoarthritic and entheseal changes within the upper limbs of post-medieval rural villagers from the Netherlands (Palmer et al. 2016). Coincidental, Palmer et al. have been studying the same population of post medieval Middenbeemster for their research that is being used within this study (Palmer et al. 2016). Osteoarthitis is a pathology occurring in synovial joints that is affected by physical activity (Pearson and Buikstra, 2006; in Palmer et al. 2016), and entheseal changes, also called enthesopathies or musculoskeletal stress markers, are the attachment sites of muscle onto bone, whose morphology is thought to correlate with muscle use and by expansion, physical activity (Churchill and Morris, 1998). For this example the focus lies on entheseal changes since these bone morphological changes are not related to any pathology, but just too physical activity. Just like with the platymeric and platycnemic indices that are used within comparison of the lower limbs between rural and urban post medieval populations, physical activity plays a role in forming/adapting the bone morphology of these musculoskeletal stress markers from the upper limbs. Comparisons between entheseal changes are made within Palmer et al. to determine the amount of mechanical loading and physical activity rural individuals have experienced within their lifetimes to see if the results support the hypothesis that the majority of the rural population of Middenbeemster indeed engaged in high levels of physical activity/manual labour (Palmer et al. 2016).

What is also shown within Palmer et al. is that it is possible to study differences in bone morphology within the human individuals themselves, in the form of asymmetry within the skeletal remains. For example, a lack of asymmetry could indicate higher physical stress, yet so could left-side dominance, as in many farming activities the right hand guides the movement while the left hand provides the brunt of the force (Palmer et al. 2016). If this fact applies to the lower limb bones as well, then it has yet to be determined, meaning left and right lower limbs should be statistically tested for significant differences as well within this study.

Activity reconstruction is used in combination with archaeology to research socio-economic environments. Research into the consequences of medieval socioeconomic developments using skeletal remains has been performed in several parts of the world (Schats 2016, 14). Socioeconomic environments in a rural area and an urban area from the post medieval time period are expected to be different from each other in the Netherlands. Activity reconstruction will shed a light on these socioeconomic differences and will therefor explain possible differences or correlations. In this research the possible differences in activity patterns/indices between the rural and urban populations and possibly between the males and females, are possibly linked to the socioeconomic environment.

Activity reconstruction based on skeletal remains will never show what an individual's activities throughout his life have been on a specific level. However, looking at the general picture of lifestyle by observation of multiple joints, prevalence, and severity, all within the context of population and demographics, provides important perspective (Larsen 2015. 185-186). In other words: studying the lower limbs of an individual will not result in an estimated profession or labour category, but will give us an general idea of the strain and mobility that said individual has experienced throughout its life, which in turn can be linked to different socioeconomic environments that exist within rural and urban context.

2.2 Bone morphology:

In this research the differences in bone morphology within the lower limbs are compared, specifically the platymeric and platycnemic indices. To explain the possible differences that could occur, it is necessary to first explain the way bone morphology changes and why these changes occur. Populations with rounder leg bone morphology (diaphyseal shape) are considered to have experienced less strain on their bones than individuals with bone flattening indicating directional muscle action and associated bone deposition (Pomeroy and Zakrzewski 2009).

A great deal of evidence has accrued in support of the notion that bone adapts to and is shaped by its mechanical environment (Larsen 2015, 214). In the present time evidence of bone adaption can be found by examining the bones of professional athletes. Individuals who tend to experience an increase in exercise or use one limb dominantly, for example a professional tennis player, will show bone adaption and/or differences in skeletal mass and structure when compared to the average individual (Larsen 2015, 214-215). Ruff et al. (2006) discusses that bones can be understood and modelled akin to engineering beams. Just like those beams, bones have to be rigid (resist deformation) and strong (resist breaking) to be able to withstand mechanical loading, mainly torsional and bending forces (Larsen 1977; Inskip 2013; Ruff et al. 2006; Schats 2016, 44). Individual skeletal elements have an irregular geometric structure, and a range of forces usually acts on the bone in normal physiological activities, such as running and walking. Therefore, the largest and most common loading parameters affecting the human skeleton are bending and torsion, especially for the long bones (Larsen 2015, 215). Applying this fact, Larsen (2015) states that in long bones and in some other elements of the human skeleton, the cross-sectional area and the manner in which bonetissue is distributed about its long axis reflect mechanical/functional behaviour (Larsen 2015, 217). Hence why this study uses the platymeric and platycnemic indices as main measurements to provide the data necessary to compare rural and urban lower limb long bones. The cross-sectional diaphyseal shape of these proximal points in both long bones are located on locations where mechanically wise the magnitude of stresses on the long bone should be the highest, which means that increased mechanical loading should trigger bone adaption on these points the most to cope with the increases of stress (Larsen 2015, 216-217; Ruff et al. 2006). This means that when considering the differences in physical labour and mobility patterns and thus the mechanical loading applied on the long bones between rural and urban areas, the human skeleton and therefore the bone morphology around the platymeric and platycnemic indices should adapt as a result of these differences. It must be kept in mind however that other influences do affect bone morphology, such as pathological conditions and trauma.

The platymeric and platycnemic indexes give us numerical data that measures the mentioned flatness of the leg bone morphology which will be comparable and will also be useful for the statistical analyses that will be performed. The morphology of the lower limb bones, as they are weight bearing and thus used in locomotion, is assumed to relate mainly to mobility patterns (Schats 2016, 45). This means that the difference between rural and urban, if they are at all present, will be linked to mechanical loading and mobility patterns mainly (Wescott 2006).

3. Materials:

The materials used within this research originate from two excavation sites within the Netherlands. The rural sample consists of human skeletal remains from the Middenbeemster area within the province of North-Holland and the urban sample consists of human skeletal remains originating from the city of Zwolle from the province of Overijssel (see figure 2).

Figure 1: Map of the Netherlands with site locations and names.

The two populations consist of large groups of individuals. Naturally not all individuals can be included within the research, and therefore sample selection is required. Any individual containing a pathology affecting the lower limb bone morphology, walking/mobility girth in an abnormal way or affecting stature in an abnormal way (scoliosis, etc.), will be removed out of the samples used for this study. All non-adults and indeterminate individuals have also been excluded from the data set that is used for the comparisons. Individuals from whom the sex is not determined are excluded as well because they cannot be added to a group for comparison since females and males are kept separated within the analyses.

Non-adults are excluded because they simply have not stopped growing yet, which also brings a different kind of bone remodelling with it which does not fit the criteria required to be considered for the statistical analyses. Also they are often not yet fully grown/have fully fused bones, which would result in outliers and unusable samples. The data base should consist of only "healthy" adult females and males, which means no visible pathologies that affect bone morphology in any way should be present within the total sample size (see appendix 1 and 2).

3.1 Middenbeemster sample:

The sample from Middenbeemster, which is the rural population that has been studied for this research, originates from a cemetery near the Keyserkerk within Middenbeemster. The church in question is in use since 1623 A.D., whilst the cemetery dates from the period between 1615 A.D. and 1866 A.D. (Lemmers et al. 2013, 35). Most of the excavated human remains date from the most recent period of burials which has been found within this cemetery, which is between 1829 A.D. and 1866 A.D. In total there are more than 400 primary burials that are found within the Keyserkerk cemetery. All these remains have been analysed by the Laboratory for Human Osteoarchaeology in Leiden (Lemmers et al. 2013, 35). During this period, the Beemsterpolder where Middenbeemster lies, formed a relatively small community centered around dairy farming. They had not yet truly been affected by the industrial revolution; therefore, most labour was manual (Drukker and Tassenaar, 1997). This means that for post medieval standards, Middenbeemster can be seen as a truly rural area within the Netherlands since industrial progress was often situated within mainly urban areas. Therefore Middenbeemster can be seen as a rural socioeconomic environment which was not yet affected by urban influences, resulting in a different way of life for its people then the population from Zwolle had. It can also be considered that in the post medieval time period urban life was to be considered generally worse for an individual’s health then it was for their rural counterparts (Drukker and Tassenaar, 1997, 354).

What is also important to mention is that this skeletal collection is still unique within the Netherlands, it is one of the few well preserved collections of human skeletal material which originates from a rural area. The preservation and completeness of most graves is considered good, since from most individuals at least 75% has been preserved and after the excavation the conservation has been good as well (Lemmers et al. 2013, 47-48).

From these 400 primary burials only 204 individuals have been selected to be added to the sample (Table 3.1). The criteria from the sample selection were met by these 204 individuals which includes completeness and preservation of the lower limbs or just one of the bones, there were no pathologies interfering with the bone morphology and the sexes of all these individuals are known.

Table 3.1: Male/female frequency and distribution within Middenbeemster.

Sex:	N frequency:	Percentage:
Female	99	48.5
Male	105	51.5
Total	204	100.0
N = Number of individuals.		

As you can see in the frequency table of the Middenbeemster site, the number of females and males is fairly equal (table 3.1). The individuals do not all have useable left and right lower limb. These individuals have been also added to the Middenbeemster sample as long as there was at least one index available for the statistical analyses. The amount of limbs will not be an exact divide for left and right lower limbs because of this fact.

As seen in the frequency table with siding, the limbs do not correlate with the number of individuals as expected since some long bones are missing (Table 3.2). The platycnemic index is slightly more represented than the platymeric is, but this does not influence the comparison between the females and males or the two populations in any way since the difference is not significant and both the platymeric and platycnemic indices both have a large enough sample size.

Table 3.2: Left/right lower limb distribution for both the platymeric and platycnemic indices.

Index:	Side/total:	N frequency:	Percentage:
Platymeric	L	167	51.5
	R	157	48.5
	T	324	100.0
Platycnemic	L	182	49.5
	R	186	50.5
	T	368	100.0
N = Number of bones, L = Left, R = Right, T = Total number of bones per index.			

3.2 Zwolle sample:

The Zwolle sample originates from a church called the Broerenkerk. This sample is the urban sample within this study. The sample collection originates from an excavation from 1987 to 1988 (Clevis and Constandse-Westerman 1992, 13).The conservation of the human skeletal materials found within the church was optimal, which even led to human hair being preserved as well and in some rare cases even some soft tissue and the eyes (Clevis and Constandse-Westerman 1992, 22). The burials within the Broerenkerk from Zwolle date from the 17th century to the early parts of the 19th century. To be more specific the oldest grave dates back to 1681 A.D. and the youngest grave dates from 1828 A.D. (Clevis and Constandse-Westerman 1992, 23-24). For the youngest graves within the church, documentation in the form of a burial book from the Broerenkerk is present, which means the youngest graves from the early 19th century have specific dates of burial (Clevis and Constandse-Westerman 1992, 23-26).

Since Zwolle is an urban area, class differences are more apparent within this population. It should be taken in consideration that being buried within a church often means that the individuals buried there can be considered of a higher class/status. However within the Broerenkerk graves this class difference is less apparent. The fact is that Zwolle has a multitude of churches which contain burials and that the churches had their own individual costs which means that the higher classes often chose to be buried in the Grote Kerk, which is the higher status/class church within Zwolle (Clevis and Constandse-Westerman 1992, 36-37). The Broerenkerk from which this collection originates was not one of the higher class burial churches and could be considered more middle class like socioeconomic wise when comparing the known prices for burials within this church with prices for burial within the other churches in Zwolle (Clevis and Constandse-Westerman 1992, 36-39). To conclude; the individuals buried within the Broerenkerk can be considered equal to the individuals from Middenbeemster class wise, yet it is also a fact that getting buried within a church still has its price, meaning that the poorer low classes are less to not at all represented within the Zwolle collection from the Broerenkerk (Clevis and Constandse-Westerman 1992).

After sample selection, it is possible to conclude that allot less individuals passed the criteria. This is due to the fact that a higher amount of pathologies and abnormalities where present within the collection, possibly this is a result of the less healthy environments that post medieval urban individuals experienced when compared to rural areas within the Netherlands (Drukker and Tassenaar 1997). This means that the sample size from Zwolle is only a fifth of the size that the Middenbeemster sample provided (table 3.3). This is not a problem however since minimum total sample size (sample size > 50) for statistical analyses has been reached (table 3.3) (Fletcher and Lock 2005).

Table 3.3: Male/female frequency and distribution within Zwolle.

Sex:	N frequency:	Percentage:
Female	25	49.0
Male	26	51.0
Total	51	100.0
N = Number of individuals.		

Just like the Middenbeemster sample the amount of lower limbs for both sides do not correlate with the number of individuals, but the difference is because of the optimal conservation less apparent (table 3.4). Unlike the Middenbeemster sample however there is almost no difference between the distribution in platymeric and platycnemic indices apart from the platymeric indices from the right sided limbs (table 3.4). The lower amount of right sided femurs within the sample could be a possible result of the loss of material that occurred during the excavation, since the conservation was optimal meaning femurs should have been found (Clevis and Constandse-Westerman 1992, 17-23).

Table 3.4: Left/right distribution for both the platymeric and platycnemic indices.

Index:	Side/total:	N frequency:	Percentage:
Platymeric	L	42	55.3
	R	34	44.7
	T	76	100.0
Platycnemic	L	45	50.5
	R	44	49.5
	T	89	100.0
N = Number of bones, L = Left, R = Right, T = Total number of bones per index.			

3.3 Total sample size:

The total sample size consist of 255 individuals which are unfortunately not evenly divided between the two locations. The urban sample from Zwolle contains only 20% of the total number of individuals, whilst Middenbeemster is represented in much greater numbers with around 80% of the total individuals (table 3.5).

Table 3.5: Total sample distribution.

Site:	N frequency:	Percentage:
Middenbeemster	204	80.0
Zwolle	51	20.0
Total	255	100.0
N = Number of individuals.		

When considering the distribution of the sexes however, it is shown that the distribution is around 48.6% for the total female count and 51.4% for the total male count (table 3.6). Since this distribution is around 50% for both sexes in the total sample and this also occurs within each individual sample, there will not be an over representation of one of the sexes which could influence the results when comparing urban versus rural.

Table 3.6: Male/female distribution in percentage.

Sex:	N frequency:	Percentage:
Female	124	48.6
Male	131	51.4
Total	255	100.0
N = Number of individuals.		

When considering the distribution for the lower limb sides (left and right), it is shown that the samples have an even distribution here as well. The total sample size for the platycnemic index is however greater in number with a total of 457 variables compared to the 400 of the platymeric index. This difference will not influence the study however since both sample sizes are considered numerous enough to apply parametric testing if possible. The total sample shown here shows the numbers of variables after filtering the samples off anomalies and abnormalities has been applied (table 3.7).

Table 3.7: Left/right distribution for both the platymeric and platycnemic indices within the total sample.

Index:	Side/total:	N frequency:	Percentage:
Platymeric	L	209	52.3
	R	191	47.7
	T	400	100.0
Platycnemic	L	227	49.7
	R	230	50.3
	T	457	100.0
N = Number of bones, L = Left, R = Right, T = Total number of bones per index.			

4. Methods:

The data necessary for this study has been recorded on so called "skeletal recording forms" which were provided for this study by the Laboratory for Human Osteoarchaeology in Leiden. These records contain all the data and measurements that have been recorded when analyzing the individual skeletal remains from both samples. The main data taken from these records is: Sex, Pathology, the value of the Platymeric index and the value of the Platycnemic index. Also some measurements from the lower limbs have been taken whenever the need arose to use these (re-calculations etc.). The skeletal recording forms have been filled out by various students from Leiden University, which means that slight differences and mistakes did occur, but all these forms have been revised, checked and corrected by staff of the Laboratory for Human Osteoarchaeology.

4.1 Measurements:

The indices that are going to be compared in this study are, as stated earlier, called the Platymeric index and the Platycnemic index. Both these indexes provide us with numerical data that shows us the amount of bone morphological adaption, which in turn shows a possible level of mobility and/or mechanical loading an individual has experienced in his life (Pomeroy and Zakrzewski 2009; Wescott 2006). The number provided shows us a certain degree of flatness located on a specific point on the femur, which is the platymeric index, and the tibia, which is the platycnemic index. The diaphyseal shape of these specific points determines how much the bone morphology has been affected by the individual itself, trough physical activity, mobility and mechanical loading. The accuracy of these geometric analyses depends on the presence of largely intact and well preserved long bones, also including size standardization (Larsen 2015, 221-222). Luckily the samples contain enough well preserved long bones which allowed the excluding of the abnormalities, pathologies and overall abnormal measurements.

When calculating the platymeric index it is necessary to have a well preserved proximal side of the femur since just the proximal part of the femur is required for the measurements that are required for the calculation. The measurements you need for the calculation of the platymeric index are the subtrochantric anterior to posterior diameter and the subtrochantric medial to lateral diameter. The platymeric index formula is as follows: Subtroch Ant-Post Diameter / Subtroch Med-Lat diameter * 100 (Pomeroy and Zakrzewski 2009, 53). This results in the platymeric index, which is a percentage indicating the flatness of the diaphyseal shape on the measured point. The lower the platymeric index is the higher the degree of flatness is, which equals more mobility/mechanical loading/activity.

The platycnemic index requires a well preserved tibia to be calculated properly. Just like the femur mainly the proximal part of the tibia is required for the measurements. The measurements you need for the calculation of the platycnemic index are the medial to lateral diameter at the nutrient foramen and the anterior to posterior diameter at the nutrient foramen. The platycnemic index formula is as follows: Med-Lat diameter at the nutrient foramen / Ant-Post diameter at the nutrient foramen * 100 (Pomeroy and Zakrzewski 2009, 53). Just like the platymeric index this calculation results in a percentage indicating the flatness of the diaphyseal shape on the measured point, which is in this case the platycnemic index. Also just like the platymeric index, the platycnemic index with a higher percentage indicates a lower degree of flatness which equals to higher levels of mobility/mechanical loading/activity.

4.2 Data collection:

Both the platymeric and platycnemic indexes had already been calculated and written on the skeletal recording forms that were provided for this study. This meant that the amount of samples added to the database could be increased since there was no need to look at the skeletal material itself. Because all data was provided, including the raw measurements of the lower limbs, it was also possible to re-calculate the indexes if deemed necessary. Multiple reasons for this form of recalculation have been encountered. The main reason was that often the forms did include the platymeric and platycnemic indexes, but sometimes these where wrongly calculated resulting in abnormal percentages that went either over 100% or under 60%. If this happened recalculation was administered which often resulted for the majority of abnormal data to be a different percentage that is below 100% which is useable within the statistical analyses. The 60% margin was only once broken, yet after recalculation still taken within the dataset. If the result stayed the same, the abnormal percentages where discarded. If the abnormalities only affected one side of the lower limbs, only one limb was discarded out of the dataset, not the entire individual. The samples provided were large enough to allow for selecting or removing individuals based on the criteria. This selection also included the exclusion of individuals affected by pathologies that affect the bone morphology, thus influencing the results which are based purely on activity patterns and mechanical loading as discussed earlier.

4.3 Database usage:

The use of the database will be paramount in the study. The samples from Middenbeemster and Zwolle gave variables which are numerous enough for statistical analyses. The variables that are used within the research are based on sex (female and male), side (left and right), and the platymeric and platycnemic indexes. The sex and side variables are considered nominal values within the database whilst the platymeric and platycnemic indexes are falling within the ordinal category since they have a numerical value which has a ranking or ordering (Fletcher and Lock 2005). Since the main goal of the statistical analyses is to determine if the variables from the two samples are significantly different, meaning that the null hypothesis can be rejected, a probability value or p-value has to be calculated. The null hypothesis and p-value are closely linked in a way that whenever the null hypothesis is not rejected a difference has occurred randomly which is shown by the p-value. The p-value expresses the chance that the observed difference happened randomly which means that the higher the p-value is, the higher the chance that the difference is occurring randomly and in fact is not statistically significant (Fletcher and Lock 2005). The p-value in osteological and archaeological research is to use a significance level of 5% ($p<0.05$), which means that if the p-value is less than 0.05 the difference can be considered statistically significant (Schats 2016, 82). The significance level of 5% is an arbitrary threshold however, and it does not have any specific inherent meaning (Schats 2016, 82). It is better to view the p-value as a way of measuring the strength of the evidence against a null hypothesis which in this study is the difference between male and female, and rural and urban (Fletcher and Lock 2005). P-values can be influenced by sample size however, in this case it means that the bigger the sample size, the more likely that the p-value will be statistically significant.

To determine if the samples from this study need to be tested either parametric or non-parametric the following facts should be considered and/or tested. Sample size should be large enough for parametric tests and should be normally distributed. The sample sizes of both populations are considered sufficient enough for parametric testing, meaning that the decision on which tests to use will be decided by the normality levels from the sample sets. Parametric tests are more powerful than non-parametric tests so should be preferred for the use of statistical analyses when the opportunity arises. To test the normality of a sample set, the Shapiro-Wilk test will be performed to determine the normality of said sample sets. If the normality is sufficient parametric testing will be used and if not non-parametric testing will be performed to avoid inaccuracies. In bioarchaeology where sample sizes are often small or not normal distributed, non-parametric tests can be particularly valuable (Schats 2016, 83).

The steps that will be taken to perform the research and comparisons between the two populations are as follows. First the normality will be checked for all separate sample sets to decide which tests will be used to calculate p-values. After this left and right limbs per sex will be compared to see if the difference is statistically significant. If the null hypothesis is not rejected, left and right limbs will be added together and side will not be playing a part within the comparisons anymore then. Afterwards the differences between male and female within the populations will be tested to see if there is a difference and after these comparisons have been completed the differences between rural and urban will be calculated by comparing Middenbeemster males with Zwolle males and the same will be done for the females of both populations. All statistical tests in this research are run with IBM SPSS Statistics 21 Software.

5. Results:

This chapter discusses the statistical results. Firstly the results from both sites will be discussed separately, starting with the Middenbeemster sample. After both sites have been discussed a site comparison will be made to see if the difference between rural and urban is statistically significant.

5.1 Results Middenbeemster:

Before any statistical test decisions (parametric/non-parametric) have been made, test of normality where required for both samples. Platymeric and platycnemic indexes will be tested separately. These tests have been done independently for the female and male sex. Left and right have also been tested independently to see if there is in the normality. Both the female and male group show a distribution that is does not allow for parametric tests to be used for the statistical analyses of the Middenbeemster sample. Non-parametric tests will be used for the Middenbeemster sample and therefor also for the calculation of the difference between the rural and urban population, even if the Zwolle sample can be analyzed using parametric tests. The statistical analyses for Middenbeemster will be performed using the Independent Samples Mann-Whitney U tests.

Firstly the difference between left and right will be statistically tested to show if the need to keep the sides apart is necessary for the testing of the differences within and between both populations. If the difference between left and right is not significant, all lower limbs will be now seen as one sample instead of a sample divided by side. The differences between sides will be tested for male and female sexes independently. If either sex has a significant difference between the lower limb sides, left and right will be kept apart for the remainder of the statistical analyses.

Table 5.1: Platymeric and platycnemic indices Middenbeemster.

Indices	Side	Males			Females		
		M	SD	n	M	SD	n
Platymeric index	L	86.61	7.56	87	85.71	8.33	80
	R	87.20	7.54	80	85.26	7.01	77
Platycnemic index	L	74.29	8.26	93	73.95	8.47	89
	R	74.37	8.10	96	75.54	7.72	90

M=mean, SD=standard deviation, n=number of measured bones, L=left, R=right.

Table 5.2: Statistical comparison of left and right lower limb means within the Middenbeemster sample.

Comparison	Males			Females		
	U	p	n	U	p	n
Femur left-right	3312.0	0.590	167	2785.5	0.301	157
Tibia left-right	4284.5	0.633	189	3517.0	0.159	179
N=number of individuals included in the test.						

When observing table 5.2 it is shown that both the female and male sample within Middenbeemster show no significant statistical differences in bone morphological shape (P-value = > 0.05) when comparing left and right lower limbs. This means that the side variable will be obsolete when testing the differences within the Middenbeemster sample. The normality of the sample after left and right are added together show that testing should continue with non-parametric tests.

When using the independent sample Mann-Whitney U test on the Middenbeemster sample to compare the female vs male lower limbs in table 5.3, it is shown that there is no significant difference in both the platymeric and platycnemic indices (P-value = > 0.05). The overview of the means of the variables visualizes this non-difference as well.

Table 5.3: Statistical comparison of male and female means within the Middenbeemster sample.

Comparison	Platymeric index			Platycnemic index		
	U	p	n	U	p	n
Male-female	11761,5	0.110	324	24164.5	0.482	368
N=number of individuals included in the test.						

Since the results show no statistically significant differences within the Middenbeemster sample, it is safe to assume that both the male and female individuals in Middenbeemster experienced generally the same amount of physical activity/mechanical loading/mobility levels.

5.2 Results Zwolle:

The Zwolle sample will also be tested for normality in the same way the Middenbeemster sample is tested. When looking at the results of the Shapiro-Wilk tests, it is shown that all variables are normally distributed across the samples, except for the left lower limb platycnemic indexes from the females within Zwolle. This does mean that all test for the Zwolle sample will be performed with non-parametric tests. Just like Middenbeemster all following statistical analyses will be done using the Mann-Whitney U tests. Just like within the Middenbeemster sample the difference between left and right has been tested first to see if the need to keep left and right separate for the remainder of the study is necessary.

Table 5.4: Platymeric and platycnemic indices Zwolle.

Indices	Side	Males			Females		
		M	SD	n	M	SD	n
Platymeric index	L	87.52	8.60	21	82.36	7.00	21
	R	85.94	8.70	19	81.84	7.40	22
Platycnemic index	L	72.54	4.83	22	72.24	8.94	23
	R	70.87	6.59	22	72.64	8.42	22
M=mean, SD=standard deviation, n=number of measured bones, L=left, R=right.							

Table 5.5: Statistical comparison of left and right lower limb means within the Zwolle sample.

Comparison	Males			Females		
	U	p	n	U	p	n
Femur left-right	172.0	0.456	40	218.5	0.761	43
Tibia left-right	184.5	0.177	44	224.0	0.510	45
N=number of individuals included in the test.						

Both the female and male sample within Zwolle show no significant statistical differences (P-value = > 0.05) when observing table 5.5. This means that the side variable will be obsolete when testing the differences within the Zwolle sample. Since the Middenbeemster sample also retained its Null Hypothesis for both the female and male sexes regarding the side differences (P-value = > 0.05), the variable side will be discarded for the total sample and each variable is now just a lower limb, not a right or left lower limb. Statistical test will from now on performed only done for female and male variables separately both within the samples and within the total sample size.

Table 5.6: Statistical comparison of male and female means within the Zwolle sample.

Comparison	Platymeric index			Platycnemic index		
	U	p	n	U	p	n
Male-female	590.0	0.014	83	929.5	0.620	89
N=number of individuals included in the test.						

When running the Mann-Whitney U test on the Zwolle sample to compare the male and female lower limbs, a significant difference is shown within the Zwolle population (table 5.6), but only in the platymeric indices. In the platycnemic indices the Null hypothesis is retained. The overview of the means in table 5.4 does show this difference as well.

The results of the Zwolle sample show that there is a statistical significant difference between the sexes within the population itself when only looking at the platymeric index variables. This means that there has been a difference in mechanical loading/mobility experienced between the males and females within Zwolle. The fact that only the platymeric index is influenced by this difference in mechanical loading and mobility can be considered mostly peculiar and requires additional research.

5.3 Site comparison:

To test the difference between rural and urban the females and males from both samples have been compared to each other, meaning only males from Zwolle will be compared to males from Middenbeemster and the same goes for the female sample groups. There is no use in testing the difference between males from Middenbeemster and females from Zwolle, since this does not tell the difference between rural and urban, but between male and female again. Firstly the male platymeric and platycnemic indexes will be tested using the Mann-Whitney U test.

As shown in the results of the Mann-Whitney U test, there is indeed a statistical significant difference observed in table 5.7 between the males from Zwolle and Middenbeemster and therefore between a rural and an urban area within the Netherlands. The difference does occur only within the platycnemic indices between males from both sites, however in both populations there is no significant difference between male and female within the platycnemic indices.

Table 5.7: Statistical comparison of Zwolle male means and Middenbeemster male means.

Comparison	Platymeric index			Platycnemic index		
	U	p	n	U	p	n
Zwolle-Middenbeemster	3293.0	0.890	207	3338.5	0.042	233
N=number of individuals included in the test.						

When observing table 5.8, the results from the statistical analyses from the females between Zwolle and Middenbeemster also show a statistical significant difference between rural and urban populations. This time the difference is seen in the platymeric indices however. It is safe to say that differences in lower limb bone morphology do occur when comparing rural and urban site within the Netherlands.

Table 5.8: Statistical comparison of Zwolle female means and Middenbeemster female means.

Comparison	Platymeric index			Platycnemic index		
	U	p	n	U	p	n
Zwolle-Middenbeemster	2479.0	0.008	200	3422.0	0.119	224
N=number of individuals included in the test.						

5.4 Results summary:

The results from within the populations and between the populations both show statistical significant differences which can be interpreted as a difference between rural and urban and a difference within urban populations. When comparing the sites, sexes and indexes in boxplots (figure 3 and 4), the differences and comparisons are distributed in an interesting way that shows the difference between rural and urban well.

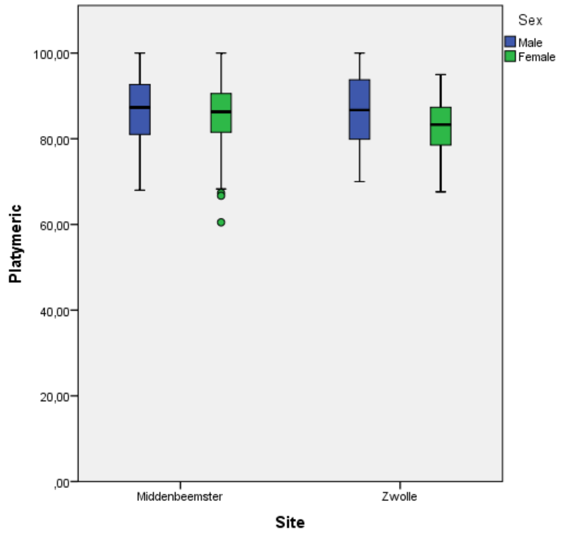

Figure 2: Platymeric index comparison for both sites and sexes.

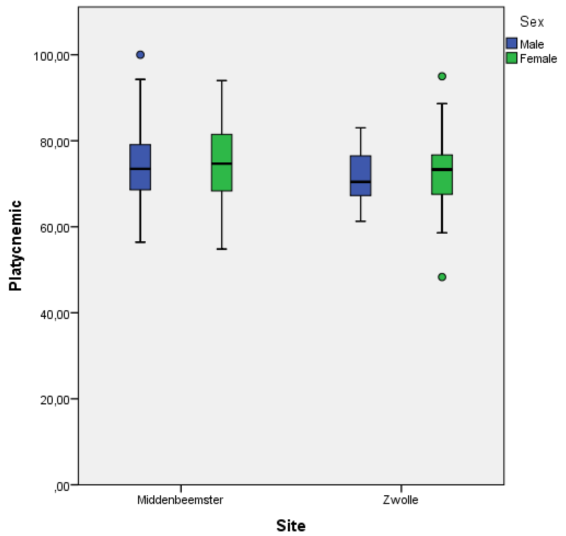

Figure 3: Platycnemic index comparison for both sites and sexes.

In conclusion, the result show a clear significant difference between Middenbeemster and Zwolle and therefore rural and urban populations. This difference is however only seen within the platycnemic index for the male lower limbs and the platymeric group for the female lower limbs. Within the populations the differences are only significant in Zwolle between the males and females, more specifically only within the platymeric indices. Middenbeemster has no clear difference between its males and females within the population.

6. Discussion:

In this chapter the results will be linked to the socioeconomic background to explain the differences that have been found. The differences between Middenbeemster and Zwolle and the differences which occur within both sites will be discussed and interpreted, whilst this chapter will also show why the socioeconomic environment plays such an important role in bone morphological adaption.

6.1 Socioeconomic background influences:

The results show us that there is indeed a difference between human lower limb bone morphology from Middenbeemster and Zwolle, and therefore a difference between rural and urban areas within the Netherlands. The results also show a difference between the female and male sexes within the population of Zwolle. These differences can be attributed to a number of factors that need to be discussed. Most likely the differences are attributed to the differences in socioeconomic environments and the labour divisions between classes within both the rural and urban areas (Drukker and Tassenaar 1997; Palmer et al. 2016; Schats 2016). Also necessary to keep in mind is the possibility that there have been unseen factors that could influence the results, even if pathologies have been excluded from the study. The lower limb bone morphology results do give an insight in the differences between rural and urban, but they will not explain all differences between both populations since they are but a small part of a much larger story.

Since “Wolff’s law of bone functional adaption”, previously known as “law of bone remodelling”, states that bone tissue places itself in the direction of functional demand, it is safe to say that both the individual himself and the living environment have a large influence on lower limb bone morphology (Larsen 2015; Ruff et al. 2006). This means that it is necessary to compare both the Middenbeemster and Zwolle socioeconomic background with each other to explain the differences seen within the lower limbs. The socioeconomic differences between rural and urban areas within the Netherlands might explain all the differences and correlations found within the total sample size.

Since the Middenbeemster sample consists of skeletons originating from an area which, according to historical sources, was engaged in non-industrialized agriculture well into the 1800s (Drukker and Tassenaar 1997; Palmer et al. 2016) whilst the sample from Zwolle has skeletal material originating from an industrialized city from the same period

(Clevis and Constandse-Westerman 1992; Drukker and Tassenaar 1997), it is possible to say that industrialization could be one of the major influences for the differences in socioeconomic environment. The industrialization within the Netherlands introduced new living standards which had both negative and positive influences for the populations living within industrialized areas. Before the industrialization, differences between rural and urban areas within the Netherlands when comparing living standards, do not support the general idea of disease riddled towns and stress-free rural areas in medieval periods (Schats 2016, 162-163). This however changes around the 1700-1800s post-medieval times when industrialization reached the cities and towns of the Netherlands (Drukker and Tassenaar 1997). This means that the city of Zwolle should show more individuals with pathologies than the Middenbeemster area, which has been discussed earlier in chapter three to be the case.

Another influence which needs to be discussed is the fact that the Zwolle sample originates, as stated earlier, from a church burial within the Broerenkerk, which means that the individuals buried there are possibly middle to higher class (Clevis and Constandse-Westerman 1992; Drukker and Tassenaar 1997). The middle and higher classes within Zwolle probably had better living standards and therefore better health and possibly less physical strain per individual. The Middenbeemster sample has a less apparent class difference since it originates from a cemetery where probably everyone from the Middenbeemster area who passed away has been buried, high- or low-class alike (Drukker and Tassenaar 1997; Lemmers et al. 2013). When interpreting the differences found within the total sample size, the class differences between the rural and urban area should be accounted for.

6.2 Interpretations:

Industrialization does bring change to a town which is not only seen in pathologies or stress markers. The labour changes which industrialization has introduced could possibly have influenced the bone morphology in the same way that the switch from hunter-gatherers to agricultural sedentary lifestyle from earlier periods had major influences on said bone morphological changes, albeit this difference will be less apparent as said example (Bridges et al. 2000; Pomeroy and Zakrzewski 2009; Wescott 2006). The fact that in the Middenbeemster area industrialization had not yet “arrived” in the 1800s, whilst it already had in Zwolle, could explain why there is a difference in lower limb bone morphology between the two areas.

The first difference that will be discussed is the difference between males and females in both populations and why they differ between rural and urban areas. The results show a difference in mobility between males and females within the city of Zwolle, but this difference does not occur in the Middenbeemster area where there is no statistically significant difference between males and females (see chapter 5). The difference between females and males can be most likely linked to two factors: first of all the labour division that is associated with the female and male sexes, and secondly the class differences within the city. Even before industrialization the labour roles within urbanized areas have been not equally divided between the sexes, whilst in the rural areas it is more common that both males and females more or less did the same amount of labour (Drukker and Tassenaar 1997; Wescott 2006). In the sample from Zwolle we do see this difference between female and male occurring in the results, but it must be noted that this sample contains only mid to high class individuals (Clevis and Constandse-Westerman 1992). This means that the lower class from Zwolle was left out from the equation, which could have influenced the results if they had been present within the sample. Often the lower classes had both the males and females working intensive labour in industrialized cities which means there would be a less apparent difference between male and female bone morphology in this group of individuals (Drukker and Tassenaar 1992). The higher and middle classes in Zwolle probably have a significant difference between female and male because the living standards plus sociological background allowed the female individuals from these classes to have different occupations/labour than their male counterparts which results in different mobility patterns. The difference between males and females within the city of Zwolle can be associated to the apparent sex differences, the higher class/status from this sample and the difference in labour which occurred within urban areas during the industrialization period. This is in stark contrast with the non-difference between male and female sexes which occurs within Middenbeemster. Post medieval Middenbeemster was, as earlier discussed, not yet industrialized in its agricultural ways which meant labour was still mainly done manually, which was done by both the male and female individuals from this population when looking at the lower limb bone morphology. This equality however is not seen in labour division because according to Palmer et al. (2016), Middenbeemster did have a gendered division in labour when looking at the upper limbs Entheseal changes (Palmer et al. 2016). The mobility patterns from females and males from Middenbeemster can be considered equal whilst the patterns from Zwolle differ from each other, however it should not be forgotten that the lower limb bone morphology adaptions which show mobility patterns and mechanical loading are only a small part of the entire story of these individuals originating from both sites.

The differences between rural and urban are apparent in both sexes. These differences can be attributed to a couple of factors. First off, since rural and urban within the Netherlands are not to be considered two whole separate worlds because of the heavy urbanisation, the differences between rural and urban in post medieval times are hard to find. The industrialization which happened in Zwolle but not in Middenbeemster can be seen as a major difference between both populations, even if the line between rural and urban can be considered thin since the Netherlands are heavily urbanized in the medieval and post medieval periods compared to other countries in Europe (Drukker and Tassenaar 1997). The mobility patterns and mechanical loading from Middenbeemster are in both the male and female sexes considered higher in both indices which means that the population from Middenbeemster was more on the move (mobility patterns) than industrialized Zwolle, which is logical when comparing travel distances within a city to travel distances in rural areas. Also labour intensity within Middenbeemster can be considered higher since it is still manual labour unlike the industrialized urban areas where labour will be less physical straining yet not less hazardous (Clevis and Constandse-Westerman 1992; Drukker and Tassenaar 1997). Another factor are the class differences which should not be forgotten, since middle and high class individuals from Zwolle probably occupied less physical occupations in their day to day life than individuals working the fields and dairy farms of Middenbeemster would have had (Palmer et al. 2016). This does mean however that the difference shown between rural and urban could also be considered a difference between social classes instead. This makes the results from this study somewhat hard to interpret since the results do show a difference, but it is not entirely clear if these differences are really attributed to the known differences between the rural and urban socioeconomic environment themselves or that these differences are more a social class difference instead. When considering the facts from the socioeconomic background of both populations and the fact that the Middenbeemster males and females both show signs of higher levels of mobility and mechanical loading than their Zwolle counterparts, it is safer to assume that there is indeed a difference between rural and urban populations overall, than only a difference between the social classes from these areas. Additional research concerning this problem is required.

7. Conclusion:

This study investigated what the differences between a rural and an urban area dating from the post-medieval period are, when looking at the activity patterns as reflected in the lower limbs bone morphology. To answer this question two samples originating from Middenbeemster (rural) and Zwolle (urban) have been compared with each other. Also the differences between male and female lower limbs has been statistically tested to see what kind of impact the division of labour had on both the male and female sexes when comparing them within the same population.

The results show that there are indeed differences between males and females within the population, but only within the Zwolle sample was this difference statistically significant. This difference is mainly attributed to the division of labour between the sexes in the middle to higher classes within an urban socioeconomic environment and the industrialization of Zwolle. The Middenbeemster sample does not have a significant difference between the males and females within the same population, which has been attributed to the fact that both male and female individuals carried an equal share of the workload and because a class difference has been less apparent within this population.

To answer the main question, “what are the differences in activity patterns as reflected in the lower limbs morphology between a collection of urban individuals from the city of Zwolle and the rural individuals of the Middenbeemster, and can these be related to the socio-economic environment?”, both the males and females from both populations have statistically significant differences between the rural and urban populations. The amount of mechanical loading and mobility is higher in the rural population however, which suggests that the people from Middenbeemster experienced more physical strain in their lifes. This is attributed to the fact that the individuals from Zwolle lived in a more industrialized, so less manual labour intensive socioeconomic environment and the fact that the Zwolle sample consists of mainly middle to high class individuals which also influences the amount of physical labour an individual experiences. Travel distances should also be considered less far for urban areas compared to rural areas which influences the mobility patterns as well. The biggest difference socioeconomic wise is however the fact that Middenbeemster did not yet experienced the changes from the industrialization that already had happened within Zwolle, which can be considered the main influencing factor for the differences in lower limb bone morphology between the two populations.

To demonstrate the differences between rural and urban areas within the Netherlands further, additional future research is required. First of all a similar study could be done with multiple sources from the same city to fully encompass all social classes within the urban and rural areas that are going to be compared. Additionally, the upper limbs could also be studied to give a more complete image of the differences since it was demonstrated in the discussion that whereas this study states that there are no differences between male and female individuals within a rural population, an upper limb study did show division between the sexes (Palmer et al. 2016). Possible future researches should also be done in correlation with other human skeletal remains studies, like dental wear differences or pathology researches, especially when considering that the industrialization period from post medieval times had huge influences on the individuals experiencing these changes. The combination of multiple studies done on both the Middenbeemster and Zwolle collections should give a bigger insight on the differences between rural and urban areas within the Netherlands.

Abstract:

This Bachelor thesis studies the differences in lower limb bone morphology between post medieval rural and urban populations within the Netherlands. To demonstrate these differences two human skeletal remains collections originating from Middenbeemster (rural) and Zwolle (urban) have been compared statistically. The study presented within this thesis aims to link possible differences within lower limb bone morphology to the socioeconomic environments, where the introduction of industrialization is one of the major changes compared to late medieval socioeconomic environments is an important factor. These new changes to the areas in which these populations lived their lives, happened quite differently for both the rural and urban areas which should results if these differences are indeed visible within the human skeletal remains.

Post medieval Zwolle and Middenbeemster both experienced the changes that the industrialization brought to the Netherlands differently, whereas Zwolle was industrialized whilst Middenbeemster did yet have to feel the “arrival” of industrialization, which means differences between the rural and urban areas should exist. Most differences between rural and urban areas are known from historical context. Looking at the human skeletal remains to see if there are bone morphological differences between rural and urban populations however, could shed some more light on the different socioeconomic environments present within the Netherlands. Lower limb bone morphology is a small part of this but nevertheless important because it gives an insight on the mobility patterns and the amount of mechanical loading experienced by the individuals living in both Middenbeemster and Zwolle.

The study shows that industrialization, rural and urban life and class differences between and within the populations indeed have an impact on bone morphological changes within the lower limbs. This means that differences in mobility and mechanical loading are present between and within both populations.

Bibliography:

Bridges, P.S. Blitz, J.H., Solano, M.C., 2000. Changes in Long Bone Diaphyseal Strength with Horticultural Intensification in West-Central Illinois. *American Journal of Physical Anthropology* Volume 112 (2), 217-238. https://doi.org/10.1002/(SICI)1096-8644(2000)112:2<217::AID-AJPA8>3.0.CO;2-E

Churchill, S.E. and Morris, A.G., 1998. Muscle marking morphology and labour intensity in prehistoric Khoisan foragers. *International Journal of Osteoarchaeology* Volume 8 (5). https://doi.org/10.1002/(SICI)1099-1212(1998090)8:5<390::AID-OA435>3.0.CO;2-N

Clevis, H., Constandse-Westerman, T., 1992. De Doden Vertellen. *Opgraving in de Broerenkerk te Zwolle 1987-88.* Zwolle: Stichting Archeologie Ijssel/Vechtstreek, 12-57.

Drukker J.W. and Tassenaar V. 1997. Paradoxes of Modernization and Material Well-Being in the Netherlands during the Nineteenth Century. In: *Health and Welfare during Industrializatio*, RH Steckel, R Floud (eds). Chicago: University of Chicago Press, 331–378. https://doi.org/10.7208/chicago/9780226771595.001.0001

Fletcher, M. and Lock, G., 2005. Digging numbers: *Elementary statistics for archaeologists*. Oxford: Oxford Univ School of Archaeology.

Frost, H.M., 1990. Skeletal Structural Adaptions to Mechanical Usage (SATMU): 1. Redefining Wolff's Law: The bone Modeling Problem. *The Anatomical Record* Volume 226 (4), 403-413. https://doi.org/10.1002/ar.1092260402

Larsen, C.S. 1995. Biological changes in human populations with agriculture. *Annual Review of Anthropology* Volume 24 (1), 185-213. https://doi.org/10.1146/annurev.anthro.24.1.185

Larsen, C.S., 2015. *Bioarchaeology: Interpreting Behavior from the Human Skeleton.* Cambridge: Cambridge University Press.

Lemmers, S.A.M., Schats, R., Hoogland, M.H.L., Waters-Rist, A.L., 2013. *De begravingen bij de Keyserkerk te Middenbeemster*. Leiden: Laboratory for Human Osteoarchaeology, Leiden University, 35-60.

Lewis, M.E., 2002. Impact of industrialization: comparative study of child health in four sites from medieval and postmedieval England (A.D. 850-1859). *American Journal of Physical Anthropology* Volume 119 (3), 211-223. https://doi.org/10.1002/ajpa.10126

Palmer, J.P.A., Hoogland, M.H.L., Waters-Rist, A.L., 2016. Activity Reconstruction of Post-Medieval Dutch Rural Villagers from Upper Limb Osteoarthritis and Entheseal Changes. *International Journal of Osteoarchaeology* Volume 26 (1), 78-92. https://doi.org/10.1002/oa.2397

Pomeroy, E. and Zakrzewski, S.R., 2009. Sexual dimorphism in diaphyseal cross-sectional shape in the medieval Muslim population of Écija, Spain, and Anglo-Saxon Great Chesterford, UK. *International Journal of Osteoarchaeology* Volume 19 (1), 50-65. https://doi.org/10.1002/oa.981

Ruff, C., Holt, B., Trinkhaus, E., 2006. Who's afraid of the big bad Wolff?: "Wolff's Law" and bone functional adaption. *American Journal of Physical Anthropology* Volume 129 (4), 484-498. https://doi.org/10.1002/ajpa.20371

Schats, R., 2016. Life in Transition: *An osteoarchaeological perspective of the consequences of medieval socioeconomic developments in Holland and Zeeland (AD 1000-1600)*. Leiden: Leiden University.

Stock, J. and Pfeiffer, S., 2001. Linking structural variability in long bone diaphysis to habitual behaviors: Foragers from the southern African Later Stone Age and the Andaman Islands. *American Journal of Physical Anthropology* Volume 115 (4), 337-348. https://doi.org/10.1002/ajpa.1090

Wescott, D.J., 2006. Effect of Mobility on Femur Mid-shaft External Shape and Robusticity. *American Journal of Physical Anthropology* Volume 130 (2), 201-213. https://doi.org/10.1002/ajpa.20316

White, T.D. and Folkens, P.A., 2005. *The Human Bone Manual.* London: Elsevier Academic Press.

List of figures:

List of tables:

List of appendices:

Appendix 1:

Site.	Feat. Nr.	Find Nr.	Sex.	Side.	Platymeric	Platycnemic.
Z	2	X	M	L	79.4	67.4
				R	76.4	66.3
Z	3	X	M	L	93.93	70.27
				R	88.23	66.66
Z	12	X	F	L	88.66	62.96
				R	91.6	67.53
Z	13	X	M	L	X	71.06
				R	X	66.45
Z	14	X	M	L	X	70.0
				R	X	64.5
Z	15	X	F	L	X	58.7
				R	78.5	61.7
Z	20	X	M	L	88.0	80.0
				R	82.0	77.0
Z	22	X	F	L	83.3	81.5
				R	86.7	71.4
Z	26	X	M	L	86.49	81.59
				R	85.99	X
Z	29	X	F	L	86.2	73.3
				R	86.2	74.2
Z	31	X	M	L	87.76	78.10
				R	82.43	78.85
Z	32	X	F	L	85.0	72.0
				R	90.0	74.0
Z	34	X	M	L	86.7	73.3
				R	86.7	66.7
Z	35	X	M	L	X	69.63
				R	X	67.91
Z	36	X	F	L	70.96	68.96
				R	78.78	80.0
Z	38	X	M	L	100.0	76.0
				R	99.0	75.0
Z	39	X	M	L	89.7	75.9
				R	86.2	78.6
Z	42	X	F	L	X	70.13
				R	X	66.94
Z	44	X	M	L	96.3	X
				R	100.0	X
Z	45	X	F	L	81.8	75.9
				R	90.3	85.7

Z	49	X	M	L	X	63.3
				R	X	61.29
Z	50	X	M	L	76.67	77.41
				R	70.0	81.25
Z	51	X	F	L	89.3	75.0
				R	83.3	76.7
Z	52	X	F	L	88.0	65.0
				R	80.8	64.0
Z	53	X	M	L	73.66	80.33
				R	74.6	82.3
Z	54	X	M	L	92.0	67.1
				R	99.0	65.9
Z	55	X	F	L	X	79.3
				R	83.3	75.9
Z	63	X	M	L	96.77	X
				R	96.55	X
Z	68	X	F	L	82.75	75.0
				R	79.32	76.0
Z	69	X	F	L	73.5	67.3
				R	75.0	68.8
Z	70	X	M	L	89.1	73.3
				R	80.4	71.4
Z	77	X	M	L	78.0	71.0
				R	75.0	65.0
Z	86	X	M	L	96.4	70.6
				R	83.9	70.6
Z	87	X	F	L	X	83.44
				R	X	78.63
Z	90	X	M	L	99.36	72.98
				R	X	70.12
Z	94	X	M	L	72.05	X
				R	X	83.0
Z	105	X	F	L	69.69	X
				R	71.88	X
Z	112	X	F	L	75.8	64.5
				R	67.6	67.7
Z	114	X	F	L	78.8	70.4
				R	80.06	76.8
Z	115	X	F	L	83.69	87.20
				R	78.57	88.64
Z	117	X	F	L	84.0	63.1
				R	X	X
Z	118	X	F	L	69.69	75.86

				R	75.0	73.33
Z	119	X	F	L	85.7	58.6
				R	78.6	48.3
Z	121	X	F	L	85.5	69.3
				R	94.0	70.4
Z	125	X	M	L	76.3	67.6
				R	85.7	69.4
Z	130	X	F	L	81.66	X
				R	90.08	X
Z	131	X	M	L	93.61	X
				R	88.26	X
Z	205	X	M	L	85.71	69.69
				R	92.59	67.64
Z	207	X	F	L	94.97	68.97
				R	90.56	74.48
Z	247	X	M	L	X	69.23
				R	X	63.16
Z	256	X	F	L	90.5	95.0
				R	70.4	76.9

Appendix 2:

Site.	Feat. Nr.	Find Nr.	Sex.	Side.	Platymeric	Platycnemic.
MB	29	24	M	L	73.0	63.9
				R	72.2	58.3
MB	S034	V0074	M	L	82.8	61.8
				R	77.4	58.3
MB	S040	V0064	F	L	82.14	82.60
				R	82.14	79.26
MB	S45	V055	F	L	73.5	79.3
				R	96.6	86.2
MB	53	290	F	L	X	72.41
				R	X	X
MB	56	61	F	L	89.28	79.31
				R	86.67	73.33
MB	S59	V133	M	L	81.1	71.4
				R	76.3	76.5
MB	S060	V0037	F	L	85.0	81.0
				R	82.1	85.0
MB	64	50	M	L	88.88	69.7
				R	X	86.2
MB	S70	V67	M	L	X	68.59
				R	97.47	73.39
MB	S083	V0075	F	L	87.1	71.0
				R	87.1	74.2
MB	S084	V0113	F	L	X	80.15
				R	X	87.86
MB	88	94	F	L	96.15	72.41
				R	88.46	77.78
MB	92	124	M	L	81.0	77.7
				R	86.0	74.6
MB	S093	V0126	M	L	85.9	80.48
				R	87.3	78.0
MB	97	156	F	L	X	74.07
				R	X	70.37
MB	S100	V0159	M	L	89.98	72.55
				R	91.66	76.97
MB	s101	131	F	L	85.7	80.9
				R	81.5	81.8
MB	107	148	F	L	87.9	X
				R	85.7	X
MB	S108	V0192	M	L	90.0	71.4
				R	90.1	72.7

MB	110	213	F	L	X	76.92
				R	79.31	80.8
MB	121	211	F	L	83.3	X
				R	83.1	79.2
MB	126	184	F	L	X	77.92
				R	X	85.05
MB	126	184	F	L	89.3	69.9
				R	88.6	64.1
MB	S137	V0491	F	L	90.7	X
				R	X	62.8
MB	S144	V222	M	L	99.96	71.51
				R	99.03	82.35
MB	S149	V0280	F	L	83.6	75.6
				R	75.9	66.9
MB	149	280	F	L	96.15	68.9
				R	85.1	68.96
MB	S151	V0666	F	L	60.5	75.4
				R	72.0	76.4
MB	S153	V0435	M	L	90.0	73.53
				R	87.5	73.55
MB	155	0196:A	M	L	X	X
				R	71.0	100.0
MB	155	1509	F	L	74.0	72.0
				R	71.0	73.0
MB	S157	V433/0470	F	L	70.59	X
				R	72.22	X
MB	158	427	M	L	96.0	X
				R	85.0	X
MB	S160	V0613	F	L	88.0	62.1
				R	88.0	65.5
MB	S162	V0316	M	L	X	78.16
				R	X	65.85
MB	170	660	F	L	70.7	62.1
				R	73.5	61.6
MB	S174	V0408	F	L	86.67	68.57
				R	83.87	72.72
MB	S180	V432	M	L	X	61.7
				R	X	60.4
MB	S183	V0311	F	L	X	68.1
				R	X	71.1
MB	186	411	M	L	X	64.86
				R	X	58.97
MB	192	636	F	L	X	94.0

				R	X	87.0
MB	S194	V0440	M	L	88.5	73.48
				R	90.16	72.80
MB	S195	V0588	F	L	82.0	83.0
				R	79.0	85.0
MB	198	601	F	L	76.8	63.2
				R	82.1	73.1
MB	S202	V0284	F	L	71.97	80.90
				R	X	X
MB	S0205	V0363	M	L	78.50	65.50
				R	85.31	68.57
MB	S207	V0334	F	L	93.10	66.67
				R	86.21	62.50
MB	209	342	M	L	88.7	64.2
				R	83.3	65.3
MB	S216	V0233	F	L	83.3	66.7
				R	90.0	74.2
MB	220	232	F	L	X	80.77
				R	X	81.48
MB	225	286	M	L	83.3	71.4
				R	90.0	73.3
MB	226	282	M	L	74.29	77.14
				R	79.41	72.97
MB	S228	V0343	M	L	88.15	72.96
				R	78.37	73.04
MB	233	304	M	L	87.2	66.2
				R	91.2	74.0
MB	S234	V0319	F	L	86.7	72.0
				R	89.2	84.6
MB	235	339	M	L	88.2	76.5
				R	93.9	75.6
MB	236	335	M	L	82.35	60.98
				R	90.91	65.0
MB	237	348	M	L	91.67	63.80
				R	86.11	62.50
MB	239	V0369	M	L	X	66.19
				R	X	68.03
MB	240	362	M	L	90.32	82.35
				R	96.55	77.14
MB	242	338	M	L	87.10	70.59
				R	87.10	72.73
MB	243	381	F	L	94.93	66.54
				R	99.52	X

MB	247	V0379	M	L	88.6	89.9
				R	95.8	80.6
MB	249	394	M	L	87.1	84.4
				R	93.1	84.4
MB	S250	V0402	M	L	84.85	70.59
				R	90.32	71.88
MB	251	624	M	L	87.5	79.4
				R	88.2	75.0
MB	s253	466	M	L	85.29	80.56
				R	93.94	81.82
MB	S254	V0357	M	L	77.4	67.61
				R	X	X
MB	S257	V1006	M	L	93.5	65.0
				R	100.0	62.2
MB	S260	V1503	M	L	X	73.6
				R	X	77.1
MB	261	422	M	L	78.7	70.2
				R	81.3	70.8
MB	262	448	M	L	99.67	69.57
				R	X	X
MB	269	1032	M	L	80.00	64.70
				R	79.41	72.72
MB	S270	V1067	M	L	93.3	69.7
				R	95.5	68.9
MB	S271	V0506	M	L	X	81.6
				R	X	77.6
MB	278	584	F	L	86.67	81.48
				R	83.33	82.75
MB	281	542	M	L	X	71.8
				R	X	69.7
MB	S285	V452	M	L	85.29	73.68
				R	91.18	71.78
MB	289	477	M	L	93.5	X
				R	96.7	73.5
MB	290	472	M	L	92.3	71.4
				R	88.8	78.7
MB	S292	V1526	M	L	X	72.04
				R	X	71.69
MB	294	V0487	F	L	98.67	86.47
				R	79.69	85.49
MB	S297	V0498	M	L	97.07	73.73
				R	94.4	75.47
MB	301	571	F	L	93.3	88.0

				R	93.0	88.0
MB	302	509	F	L	83.3	64.3
				R	80.6	84.0
MB	306	561	M	L	90.0	66.6
				R	100.0	68.42
MB	S309	V0616	F	L	81.8	64.7
				R	79.4	61.7
MB	310	550	M	L	85.29	70.27
				R	X	70.27
MB	S313	V0926	M	L	90.49	82.31
				R	87.24	75.76
MB	S317	V0649	M	L	83.31	74.37
				R	78.54	85.68
MB	S319	V0669	F	L	87.10	70.00
				R	83.87	71.00
MB	S321	V0664	M	L	X	79.41
				R	X	77.14
MB	324	671	M	L	96.77	X
				R	84.85	X
MB	325	676	M	L	X	68.6
				R	X	70.6
MB	327	758	F	L	X	65.6
				R	X	72.4
MB	S331	V735	F	L	93.8	65.6
				R	84.4	71.9
MB	337	714	M	L	X	86.69
				R	X	77.98
MB	S338	V0721	F	L	92.04	72.48
				R	86.66	72.81
MB	339	728	F	L	X	75.5
				R	85.4	73.3
MB	342	737	M	L	83.4	79.5
				R	95.7	80.0
MB	S344	V0730	F	L	87.0	56.3
				R	87.3	73.4
MB	S345	V757	F	L	72.0	64.0
				R	85.0	80.0
MB	346	733	F	L	95.5	82.0
				R	99.8	81.0
MB	S349	V0752	M	L	84.38	90.32
				R	77.14	83.87
MB	355	748	F	L	83.6	70.3
				R	85.7	68.6

MB	356	864	F	L	88.88	62.85
				R	82.75	62.5
MB	S357	V745	F	L	X	75.8
				R	X	71.8
MB	359	760	F	L	93.5	73.3
				R	93.5	75.0
MB	360	762	F	L	87.8	72.3
				R	81.0	78.1
MB	S363	V0766	M	L	93.33	64.86
				R	80.0	75.0
MB	S368	V0794	M	L	95.1	66.3
				R	86.6	72.3
MB	369	886	F	L	92.0	81.5
				R	92.0	73.4
MB	S371	V0790	M	L	X	94.27
				R	X	88.28
MB	372	808	F	L	89.0	75.0
				R	92.0	78.0
MB	374	861	M	L	90.0	77.0
				R	90.0	76.0
MB	375	815	M	L	93.33	68.57
				R	90.23	64.86
MB	377	811	M	L	96.8	89.2
				R	91.2	90.0
MB	379	851	M	L	80.55	80.0
				R	77.77	76.47
MB	380	821	M	L	98.01	88.78
				R	85.86	80.90
MB	S382	V0818	F	L	80.5	70.0
				R	81.8	74.7
MB	S383	880	F	L	76.67	67.74
				R	79.31	65.6
MB	S386	Vo848	F	L	86.28	X
				R	90.18	X
MB	S388	Vo914	F	L	X	76.5
				R	X	76.7
MB	390	831	F	L	87.9	62.7
				R	85.7	67.8
MB	S391	V0826	M	L	90.1	74.6
				R	98.3	79.1
MB	S392	V0829	F	L	83.3	82.2
				R	97.3	81.9
MB	394	869	F	L	X	85.0

				R	X	85.0
MB	397	892	F	L	X	77.4
				R	X	80.0
MB	401	876	F	L	87.09	X
				R	78.78	X
MB	402	907	M	L	80.0	90.0
				R	77.1	90.0
MB	S404	1139	M	L	X	83.78
				R	X	85.32
MB	405	882	F	L	85.19	61.29
				R	88.46	65.15
MB	S407	V0992	M	L	77.1	77.4
				R	80.0	77.4
MB	S409	V0909	F	L	67.34	83.41
				R	79.33	77.88
MB	S411	V0904	M	L	99.6	90.1
				R	91.2	81.2
MB	S415	V9999	M	L	83.0	X
				R	77.0	X
MB	S416	V1507	M	L	72.71	62.45
				R	75.04	62.75
MB	S420	V0936	F	L	79.18	93.24
				R	80.29	74.66
MB	S422	V0962	F	L	66.7	54.8
				R	69.7	60.0
MB	426	968	F	L	75.0	78.8
				R	81.1	83.3
MB	427	938	M	L	X	70.96
				R	X	75.0
MB	428	945	F	L	96.0	83.0
				R	84.0	76.0
MB	430	965	F	L	95.79	80.30
				R	96.87	85.22
MB	432	981	M	L	96.0	83.0
				R	X	73.0
MB	S434	V0958	F	L	X	66.0
				R	X	80.0
MB	435	929	M	L	68.42	69.44
				R	72.97	65.71
MB	S436	V0911	F	L	75.0	75.86
				R	74.2	82.1
MB	437	1501	F	L	X	84.6
				R	X	78.5

MB	441	932	F	L	91.6	68.9
				R	96.9	66.8
MB	452	985	F	L	85.2	62.7
				R	79.3	65.2
MB	453	973	F	L	X	67.86
				R	96.2	68.97
MB	S455	V0976	M	L	95.75	77.98
				R	92.13	83.23
MB	S456	V0978	M	L	74.4	75.0
				R	X	73.5
MB	S457	V0960	F	L	90.63	72.41
				R	90.32	72.41
MB	461	990	F	L	93.9	69.18
				R	86.7	75.91
MB	464	1012	M	L	76.47	X
				R	79.41	X
MB	S466	V0996	M	L	84.0	84.0
				R	83.0	85.0
MB	467	1022	M	L	100.0	56.4
				R	96.97	61.1
MB	S468	V1009	F	L	95.8	71.0
				R	100.0	85.2
MB	469	1016	M	L	X	X
				R	X	76.0
MB	S470	V1026	M	L	84.37	88.9
				R	X	82.9
MB	473	1003	M	L	93.0	72.0
				R	93.0	67.0
MB	S474	V0998	F	L	88.8	60.8
				R	85.9	61.8
MB	S476	V1054	F	L	98.40	83.60
				R	88.0	86.40
MB	S477	V1030	M	L	88.88	91.36
				R	96.74	92.11
MB	481	1046	F	L	X	69.5
				R	X	70.8
MB	482	1048	M	L	96.67	65.79
				R	100.0	65.79
MB	484	1024	M	L	81.82	67.65
				R	78.12	71.43
MB	S485	V1034	F	L	93.1	81.5
				R	89.7	76.7
MB	486	1088	F	L	82.6	67.6

				R	76.7	81.8
MB	487	1096	F	L	96.0	66.7
				R	95.8	64.3
MB	488	1037	F	L	68.29	82.14
				R	72.50	82.76
MB	490	1045	F	L	78.12	X
				R	X	X
MB	492	1039	M	L	76.47	X
				R	74.28	60.53
MB	494	1057	M	L	72.97	85.29
				R	79.41	84.37
MB	S495	V1041	F	L	91.01	X
				R	X	X
MB	S497	V1059	M	L	86.62	76.76
				R	86.93	78.17
MB	S498	V1071	F	L	81.3	81.0
				R	83.3	75.0
MB	501	1097	F	L	92.0	66.0
				R	85.0	65.0
MB	502	1062	M	L	84.0	70.0
				R	84.0	68.0
MB	504	V1109	F	L	83.3	X
				R	86.7	66.7
MB	S505	v1095	M	L	89.3	X
				R	86.2	X
MB	508	1101	M	L	68.0	66.7
				R	X	66.7
MB	S511	V1126	M	L	79.5	90.0
				R	X	X
MB	S512	V1105	F	L	84.5	67.8
				R	81.5	70.2
MB	S514	V1106	M	L	78.96	X
				R	78.41	73.28
MB	516	1122	M	L	91.10	67.41
				R	85.67	73.52
MB	518	1080	F	L	88.4	86.2
				R	88.0	79.3
MB	S519	V1113	M	L	73.0	72.0
				R	86.0	69.0
MB	520	1118	M	L	88.2	76.4
				R	94.1	74.2
MB	521	1150	M	L	81.0	70.6
				R	96.0	66.67

MB	S523	V1156	M	L	93.0	74.4
				R	80.0	70.7
MB	524	1120	M	L	85.7	73.0
				R	90.3	61.6
MB	526	1160	M	L	X	78.0
				R	X	83.0
MB	S527	V1153	F	L	X	66.5
				R	X	76.1
MB	S530	V1159	F	L	90.51	83.99
				R	90.55	83.27
MB	533	1174	F	L	92.8	74.0
				R	87.1	70.0
MB	S534	V1165	M	L	96.55	72.41
				R	96.43	78.57
MB	544	1510	M	L	90.3	X
				R	90.6	X
MB	550	1580	F	L	99.7	X
				R	93.2	83.1
MB	S552	V1186	M	L	86.0	X
				R	89.8	89.0
MB	553	1183	F	L	87.12	88.80
				R	X	89.50
MB	553	1183	F	L	87.12	88.80
				R	X	89.50