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Time to set aside 19th century tools and move to the future: Testing the Portable Osteometric Device against the osteometric board.

Eric H. Anderson
Mississippi State University, eha44@msstate.edu

Time to set aside 19th century tools and move to the future: Testing the Portable Osteometric Device against the osteometric board.

By

Eric H. Anderson

Approved by:

Anna J. Osterholtz (Major Professor)
Shawn Lambert
Molly K. Zuckerman (Committee Member/Graduate Coordinator)
Rick Travis (Dean, College of Arts & Sciences)

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Name: Eric H. Anderson

Date of Degree: May 13, 2022

Institution: Mississippi State University

Major Field: Applied Anthropology

Major Professor: Anna J. Osterholtz

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This project tested the reliability and validity of the Portable Osteometric Device Version 1 (PODv1) the Paleo-Tech Lightweight Field Osteometric Board (PaleoTech), by providing measurements of intra-observer and inter-observer error during the collection of osteometric data. The PODv1 is a device that the author invented for measuring anthropometric data from human skeletal material. This device was 3D printed and uses laser sensors with time-of-flight technology to measure distance. Twenty-three different volunteers with various osteological experience from the Mississippi State University community collect osteometric data for this project. These volunteers measured four different bones using both the POD and the PaleoTech devices over three different rounds. The results show that the PODv1 is a reliable and valid device compared to the PaleoTech. Both devices were prone to the same issues, but the PODv1 can improve on these issues with more modifications and research, unlike the current osteometric board designs.

DEDICATION

I would like to dedicate this thesis to my father Terry Neal Anderson who passed away March 12, 2020.

ACKNOWLEDGEMENTS

First off, I would like to thank all the friends I have made during my time at Mississippi State University (MSU). These friends have been essential in motivating and supporting me to complete my master thesis. They listened to me complain about my research, and there when I needed a friend to have one too many beers with. I would like to thank Dr. Anna Osterholtz for her encouragement and support during my time as a graduate student. I would like to thank my committee members Dr. Molly Zuckerman and Dr. Shawn Lambert for their support and guidance. A special thanks to Dr. Shane Miller for all his statistical analysis help. I would like to thank Dr. James Hardin for helping me find funding that allowed me to build my prototype. I would like to thank Eric Hill from the Entrepreneur Center, who helped get my project off the ground and funded. Lastly, I would like to thank the entire AMEC faculty and staff for giving me the opportunity to study here at MSU and for all their support.

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CHAPTER I

INTRODUCTION

Since the 1880s, measurements of skeletal material have been an essential part of osteological research. Long bone measurements taken using osteometric boards have become synonymous with human skeletal research. These tools are a must-have for any researcher conducting a biological profile or other skeletal analyses. Despite this, from the late 19th century onwards, these tools have had very little modification or changes to their design. Advances in technology now allow for an overhaul of the osteometric board. Using modern technology, this project created and tested a novel measuring device, the Portable Osteometric Device version 1, against an industry leading osteometric board, the Paleo-Tech Lightweight Field Osteometric Board (PaleoTech), by providing measurements of intra-observer and inter-observer error during the collection of osteometric data.

In the fall of 2019, I began developing and testing a newly reimagined 3D printed osteometric device that used laser-based measurement technology. The development process started by breaking the design down to its essential elements and determining how it operated. The traditional osteometric board consists of single board base with a fixed panel and detachable sliding panel, which an object is placed between to determine its length. Examining the design at this level shows that the board is crucial because the object's length cannot be determined without it. To transform and increase the efficiency of the design, I first began by asking how to remove this crucial aspect and still accurately measure. The answer to this question came by removing the board entirely and using laser sensors with time-of-flight technology to measure distance. After some initial concept testing, some design testing the Portable Osteometric Device version 1 (PODv1) was invented.

Statement of Problem

The osteometric board is one of the primary devices used for recording anthropometric data from human skeletal material, such as long bone length. No significant changes have occurred from the osteometric board's original 19th century design. However, there are several issues with the traditional design. They tend to be bulky and inconvenient to transport. Also, the osteometric board is expensive relative to other osteological data collection equipment and the device also requires the user to read the measurements manually, which can lead to intra- and inter-observer error, depending on how researchers read the measurement. To resolve these issues and put the osteometric board into the 21st century, I invented a new device for measuring anthropometric data from human skeletal material, specifically bone length, the Portable Osteometric Device version 1 (PODv1). This device is made through 3D printing and uses laser sensors with time-of-flight technology to measure distance. The purpose of this project was to test the reliability and validity of the PODv1 against an industry leading osteometric board, the Paleo-Tech Lightweight Field Osteometric Board (PaleoTech), by providing assessment of intra-observer and inter-observer error during the collection of osteometric data.

CHAPTER II

RESEARCH QUESTIONS

Primary Research Question

What is the reliability and validity of the PODv1 as a device for collecting osteometric data, specifically long bone length? This primary research question was answered using the following secondary research questions.

Secondary Research Questions

1. Are the long bone length measurements taken by the PODv1 reliable and valid when compared to those taken with the Paleo-Tech Lightweight Field Osteometric Board?

2. What is the intra-observer error between the long bone measurements taken with the PODv1 when compared to the measurements taken with the Paleo-Tech Lightweight Field Osteometric Board?

3. What is the inter-observer error between the long bone measurements taken with the PODv1 compared to the measurements taken with the Paleo-Tech Lightweight Field Osteometric Board?

4. Do either of the measurements taken with the PODv1 or the Paleo-Tech Lightweight Field Osteometric Board have a 2% error rate?

CHAPTER III

BACKGROUND

Osteometric Boards

Anthropometry centers on methods for measuring the human body and has been used since the early 18th century to understand more about our species (Jamison and Zegura 1974; Marks 2012, 2017). During early anthropometry research, anthropologists used osteometric devices to attempt to racially classify different groups of people and calculate ranked (i.e., inferior verses superior) intelligence levels and criminal tendencies (Marks 2012, 2017). Today, anthropologists collect anthropometric data from human skeletal material, or osteometric data, to reconstruct maximum living stature, growth and development patterns, and to estimate sex in skeletal assemblages, among other applications (e.g., Adams and Byrd 2002; DiGangi and Moore 2012; Moore 2012; Moore and Ross 2012). Since the invention of the first osteometric board, they are one of the most utilized tools for helping biological anthropologists, human osteologists, bioarcheologists, and forensic anthropologists to gather osteometric data.

Paul Broca made the first osteometric board in 1888 (Schiller 1992). Hepburn (1889) described Broca's original osteometric board design as:

> “a flat graduated board or plank, at one end of which a flat vertical upright is fixed. Against this upright part the bone to be measured is placed, while to the opposite end of the bone a right-angled triangle of wood is applied, and the length of the bone is read of up on the graduated plank” (Hepburn 1899)

Since then, few updates have been made to this original design. One update was developed by Hepburn (1899), which involved adding stabilizing elements to the design. These increased the ease of measurements taken using the modified board. This update also reduced inter- and intra-observer errors that were created by the level of difficulty involved in using Broca's design (Hepburn 1899).

Researchers and manufacturers have made some improvements to osteometric boards since the late 19th century, but they are limited in scope. The changes were intended to make the osteometric board more user-friendly, portable, and affordable. An example of these changes is the Abawerk osteometric board. The Abawerk board has two upright panels along the length and width of the board with metric ruled paper placed on the base, which is used to determine the length of skeletal material placed on the board (Geise 1986). This board design makes it easier to generate measurements and increases their precision because the ruled paper can be measured from multiple angles (Geise 1986). Commercially manufactured osteometric boards, such as those by Carolina Supply Company and Paleo-Tech, the latter of which is used in the proposed study, have made strides in developing more portable models by making them collapsible, but they are expensive (retail prices of between $75 and $825, but the majority retail for over $200). To counter this cost, some researchers have made their own osteometric boards. Naples and colleagues (2010) created an inexpensive osteometric board for the classroom. Their goal was to facilitate students' usage of osteometric boards, offering more opportunities to learn forensic methods. This osteometric board consisted of rulers, tape, glue, and cardboard (Naples et al. 2010). This option is highly affordable, but not particularly durable.

Osteometric Considerations

Osteometric data gives biological anthropologists, human osteologists, bioarcheologists, and forensic anthropologists the means to estimate sex and maximum living stature as well as quantifying differences in growth and development (e.g., comparing age at death estimates based on diaphyseal length to those derived from dental development) (Adams and Byrd 2002; DiGangi and Moore 2012; Moore 2012; Moore and Ross 2012). They can also use this information to compare their findings with metrics from other osteological analyses emphasizing the importance of reliability and validity of these measurements. Reliability refers to the measure of inter- and intra-observer error, in which an object is measured on two different occasions by at least two different observers, with little random error (Nance 1987). Validity is the degree to which a measurement consistently accomplishes its intended purpose. In other words, it is a question of how accurately and precisely the measurement taken from the osteometric board reflects the true length of the long bone, when measuring from a baseline that is accepted to be accurate (Nance 1987). This type of information must be collected methodically due to human error (both inter- and intra-observer error), instrumentation issues, and the observer's experience.

Inter- and intra-observer variation especially must be considered by researchers when examining osteometric data (Adams and Byrd 2002). The inter-observer error results from inconsistent measurements between different observers, while intra-observer error results from inconsistent measurements taken by a single observer (Adams and Byrd 2002). Generally, inter-observer error is greater than intra-observer error, and fewer errors will occur with the measurement of maximum length and breadth measurements of skeletal material (Langley et al. 2018). Acceptable error rates for anthropometry are <1.5% for intra-observer error and <2% for inter-observer error (Perini et al. 2005). Postcranial measurements classified as difficult for most observers to generate, like those of the tibia, should have less than a 3% error rate (Adams and Byrd 2002). A way to reduce the error rate when using an osteometric board is by knowing what can affect your results and properly operating it following those expectations.

Failure to understand what factors can impact an osteometric board, like humidity, will lead to errors with the measurements due to the instrument or observer (Langley et al. 2018). These may impact both reliability and validity of the measurements. Some factors are external to the observer, while some are specific to the observer. One example of an external factor is the effects of humidity on the Abawerk osteometric board (Geise 1986). Giese found that this type of board's measurement results changes depending on the amount of humidity present in the local environment during data recording. Specifically, Giese found that elevated relative humidity, of 60% and higher, made the grid paper expand and changed the measurement's outcome between .5 and 1 mm. Overall, as ambient humidity increased, so did the length of the measurements (Geise 1986). Conditions specific to the observer include the amount of experience the observer has using an osteometric board, which may generate poor reliability within the collected data. For example, Adams and Byrd (2002) conducted a study with 68 participants during the 52nd American Academy of Forensic Sciences meeting (AAFS). These participants, who had various amounts of experience with recording postcranial measurements, used both digital calipers and an osteometric board to record 22 postcranial measurements. They found that those with less experience, especially those with less than five years of experience, produced measurements with increased inter-observer error. The common errors they identified in the study included transposing numbers, decimal place errors, not zeroing out the calipers, incorrect measurement transcription, and not understanding how to take measurements following established standards (e.g., Buikstra and Ubelaker 1994). In sum, Adams and Byrd (2002) showed that experience with the equipment would increase proficiency to a certain point. However, complacency can also occur if the observer is overconfident in their skills and fails to conduct the measurements carefully (Adams and Byrd 2002).

In osteometric analysis, reliability and replicability are fundamental (Adams and Byrd 2002; Langley et al. 2018). One way to accomplish these is by restricting analyses to osteometric measures that do not require extensive experience, like maximum length measurements (Adams and Byrd 2002). These types of measurements have lower error possibilities and can help decrease inter- and intra-observer errors (Adams and Byrd 2002). However, this can greatly limit the scope of analyses incorporating osteometric data. Recognizing extrinsic or environmental factors, such as humidity that may impact error and accuracy, is also important (Albrecht 1983; Langley et al. 2018; Geise 1986). Another way is improving the tools used for collecting osteometric data so that they produce more consistent measurements, which can include using computer-assisted methods (Adams and Byrd 2002; Harris and Smith 2009). This project represents the latter aim.

Osteometric Laser: Preliminary Study

As previously stated, the purpose of this project was to test the reliability and validity of the PODv1 against the Paleo-Tech Lightweight Field Osteometric Board (PaleoTech) by providing measurements of intra-observer and inter-observer error. A preliminary assessment aimed at determining the applicability of a direct time of flight (ToF) laser measuring device was conducted in 2021 using a laser for the collection of osteometric data, specifically long bone length (Anderson and Osterholtz 2021). ToF is a method for measuring distance by determining the time it takes for photons to travel between a sensor and an object (Koerner 2021). This study used a Bosch Blaze GLM 50 C laser measure (Bosch laser) to determine if bone length measurements taken using this device were comparable to those generated with a PaleoTech board. Twenty volunteers from the Department of Anthropology and Middle Eastern Cultures (AMEC) who had both different levels of educational attainment (i.e., BA degree in progress, MA degree in progress, Ph.D. attained) in Anthropology and varying levels of experience in collecting osteometric data were incorporated into this study. These volunteers measured cast replicas of a femur and a radius using both the Bosch laser and a PaleoTech osteometric board. A Pearson R test was used to compare the relationship between osteometric data collected by the volunteers using the Bosch laser and using the PaleoTech osteometric board. Both devices showed a small correlation with the measurements taken of the radius (r=.597, n=20, p=.005) and the femur (r=.988, n=20, p=0.04). Only a small correlation was found between the measurements taken from the Bosch laser and the PaleoTech osteometric board. This small correlation is due to interobserver error associated with different levels of observed experience, potentially exacerbated by the fact that observers were not given any instruction in how to take the osteometric measurements Also, by not being anchored to a table or board, the Bosch laser had some instability -- much like Broca's original device -- which likely caused some variation within the measurements when compared to the Paleotech osteometric board. Though this study showed that collecting osteometric data with the Bosch laser required further refinements and continued testing, the results did indicate that the Bosch laser represented a comparable tool to the osteometric board (Anderson and Osterholtz 2021). This project builds on this preliminary study. The PODv1 device addresses the technical issues identified in the preliminary study by incorporating the aforementioned modifications to the design, employing volunteers with consistent experience in collecting osteometric data, and providing detailed instructions on how the measurements were to be taken and then devices to be used for the volunteers in the study.

Portable Osteometric Device

I developed and utilized a novel device for measuring long bones, the Portable Osteometric Device version 1 (PODv1) (Figure 3.1). The PODv1 was developed as a solution to the reliability and validity issues in osteometric analyses. This portable research tool is battery operated, 3D printed and uses a laser distance measuring sensor module with direct time-of-flight (ToF) technology to measure bone length with increased accuracy. The PODv1 uses a direct ToF method consisting of a transmitter and receiver. The transmitter fires a laser pulse that is reflected off an object, which is then captured by the receiver to measure photon travel time (Koerner 2021). The laser distance measuring sensor module used for this project has an accuracy of +-1mm, depending on the lighting conditions and distance being measured (AliExpress). For an error rate less than 2%, ToF distance measurement needs an object with greater than 73% reflectivity (AdaFruit 2016; Jans et al. 2020). Therefore, for increased reflectivity, the PODv1 was constructed with a white filament target area to give an 88% reflectivity to improve its reliability (AdaFruit 2016). Compared to the current conventional osteometric board design (e.g., PaleoTech), the PODv1 is smaller and has a more open design (i.e., the design is not physically connected by a base board like the PaleoTech). The dimensions of the PODv1 are approximately 115mm x 100mm x 58 mm, which makes this design easier to transport for researchers traveling to conduct fieldwork and conducting data collection in local and abroad field settings. Also, this smaller design makes the device easier to store and takes up less space than other conventional osteometric boards (Figure 3.2). The open design gives the PODv1 the ability to measure various artifacts, and nonhuman remains from .03 m to 2 m.

Figure 3.1 Portable Osteometric Device version 1 (PODv1)

Figure 3.2 PODv1 compared to PaleoTech board

The PODv1 uses two primary components: A Laser Panel and the Sliding Panel (Figure 3.3). The Laser Panel is composed of an upright panel containing the laser and control unit and the Clamp Stabilizer (Figure 3.3 a & b). The Sliding Panel component has a foldaway Sliding Stabilizer and stores all the parts for the Clamp Stabilizer (Figure 3.3 c & d).

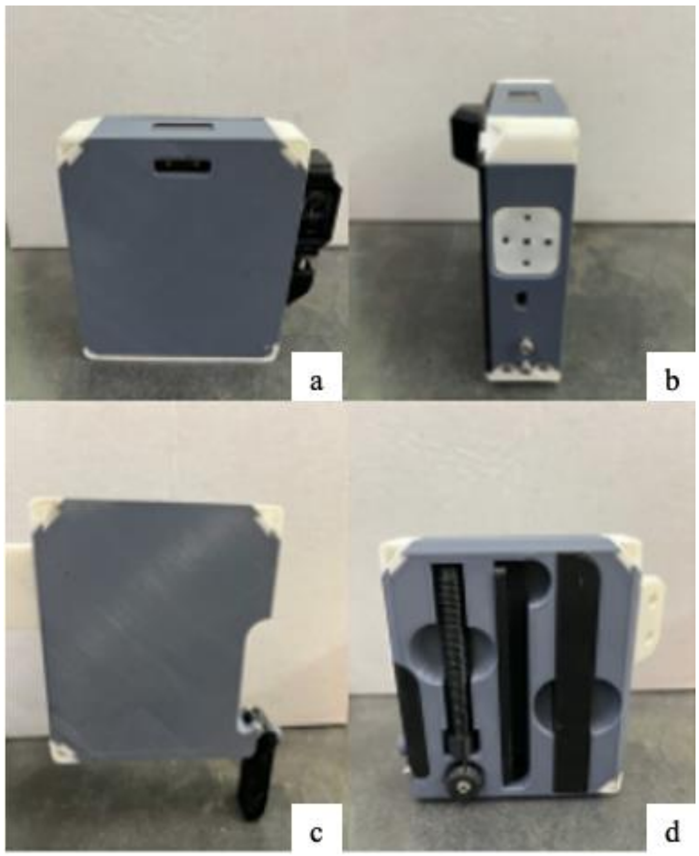

Figure 3.3 PODv1 Laser Panel and Sliding Panel

a: Front portion of the Laser Panel with laser on right side, b: Control unit on left side of the Laser Panel, c: Front of the Sliding Panel with foldaway Sliding Stabilizer on right side, & d: Clamp Stabilizer storage on the back of Sliding Panel.

The POD is set up by assembling the Clamp Stabilizer and attaching it to the Laser Panel to create a 90-degree angle, which is then placed against a table. Once this is accomplished, the

Clamp Stabilizer secures it to a table with a clamp (Figure 3.4 a). After securing it to a table, the Sliding Panel is assembled and placed against the table (Figure 3.4 b). Then, the skeletal material (or another object for measurement) is placed against the Laser Panel. The Sliding panel is then used to secure the material, and the measurement is displayed on an LCD screen (Figure 3.4 c).

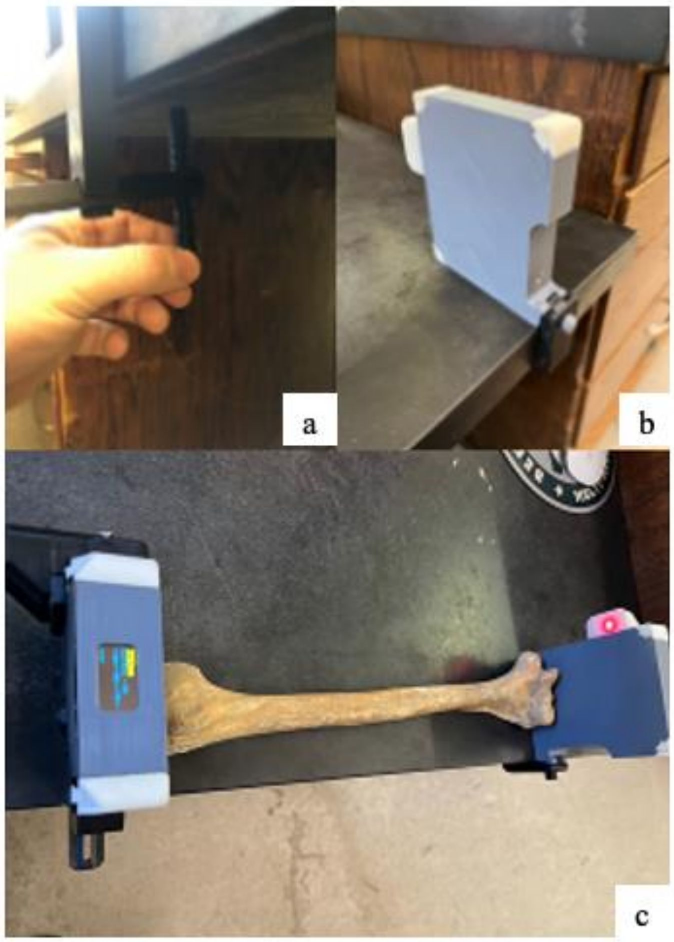

Figure 3.4 PODv1 assembly

a: Securing of the Laser Panel using the Clamp Stabilizer, b: Assembled Sliding Panel, & c: Complete assembly of the PODv1

Portable Osteometric Device Features

The PODv1 has four different operating functions: Live Mode, Precision Mode, Calibration, and History. Only the Live and Precision Modes are for measuring the length of an object. The Live Measurement is automatically engaged after turning the PODv1 on and displays a continuous measurement (Figure 3.3a). This mode displays an active 25%, midpoint, and 75% of the measured object (Figure 3.3a). It also displays the last Precision mode measurement taken under the Live measurement reading (Figure 3.3a). The Precision mode measurement takes 20 measurements and displays the average of these measurements (Figure 3.3b). The last two functions are Calibrate and History, which shows the last five Precision Mode measurements (Figure 3.3c). In order to calibrate the PODv1, ra 100mm block must be placed between the two panels during calibration.

Figure 3.5 PoDv1 display screens

a: Live Measurement display screen, b: Precision Mode, and c: Calibrate and History

CHAPTER IV

RESEARCH DESIGN

Hypotheses

The following hypotheses address research questions 1 through 4 that were outlined above.

- H1: Measurements taken by volunteers using the PODv1 and the Paleo-Tech Lightweight Field Osteometric Board for a tibia, humerus, femur, and ulna will be statistically significant between the PODv1 and Paleotech Lightweight Field Osteometric Board measurements.
    - Ho1a: The volunteers using the PODv1 1 to measure a tibia will not be statistically significant in the length measurements that they generate when compared to the Paleo-Tech Lightweight Field Osteometric Board.
    - Ho1b: The volunteers using the PODv1 to measure a humerus will not be statistically significant in the length measurements that they generate when compared to the Paleo-Tech Lightweight Field Osteometric Board.
    - Ho1c: The volunteers using the PODv1 to measure a femur will not be statistically significant in the length measurements that they generate when compared to the Paleo-Tech Lightweight Field Osteometric Board.
    - Ho1d: The volunteers using the PODv1 to measure a ulna will not be statistically significant in the length measurements that they generate when compared to the Paleo-Tech Lightweight Field Osteometric Board.

The following hypothesis addresses research question 4 that was outlined above.

- H2: The volunteers using the PODv1 and the Paleo-Tech Lightweight Field Osteometric Board will have measurements that exhibit an inter-observer error less than 2%, utilizing the measurement of the author as a baseline.
    - Ho2a: The volunteers using the PODv1 will not generate measurements that exhibit an inter-observer error less than 2%.

- Ho2b: The volunteers using the Paleo-Tech Lightweight Field Osteometric Board will not generate measurements that exhibit an inter-observer error less than 2%.

CHAPTER V

METHODS AND MATERIALS

3D Modeling and Printing Methods

3D printing technology and supporting hardware was used to create the PODv1 housing unit for the laser. This production method was the least expensive method and the easiest method for creating the housing for the PODv1 laser. The PODv1 housing was designed in Autodesk Fusion 360 CAD software. This CAD software was chosen because it is a user-friendly operating and is open-source. Once I rendered the 3D model in CAD, the PODv1 was placed into the PrusaSlicer slicing software program to be transitioned into a series of layers and a format that the 3D printer can print. This slicing software was used because it was compatible with a 3D printer that was accessible. The Creality Ender-3 V2 FDM 3D Printer with ABS (Acrylonitrile Butadiene Styrene) filament printed the PODv1 housing. ABS filament was chosen because it is the least expensive material suitable for creating the PODv1 housing.

Baseline

I proctored the volunteers participating in this research and created the baseline measurement for each of the four bones elements, specified above. The four bone elements were drawn from the Đurđevac-Sošice Comingled Collection at MSU. This collection was chosen due to accessibility and proximity to the volunteers’ location, permission of the descent community for inclusion of the remains within research contexts, and the completeness of the bone elements available. This baseline was accomplished using the traditional Paleo-Tech Lightweight Field

Osteometric Board, and measuring each of the four bone elements three different times. Then the results were averaged to create a baseline measurement for each bone. These baseline measurements were used as the true measurement. Those measurements were then compared to the measurements made by the volunteers who used the PODv1 and the PaleoTech osteometric board in order to test interobserver error and validity.

Volunteers

Volunteers were initially intended to come from Mississippi State University (MSU) and the Ohio State University (OSU) community. Unfortunately, an Institutional Review Board (IRB) approval could not be attainted in time to include any volunteers from OSU in this study. All volunteers came from the MSU community, and an IRB approval was obtained before any data was collected (IRB-21-457). Twenty-three volunteers at MSU collected osteometric data. The volunteers at MSU were required to have completed an undergraduate or graduate-level osteology course, whether at MSU or a previous degree-granting institution, or possess equivalent experience prior to data collection. In this project, equivalent experience is any training or work that focused on human remains (e.g., lab work and field school). I used a power analysis to determine the minimum number of volunteers needed for this research because of the possible limited number that would meet the requirement to participate in this study. The power analysis consisted of a paired sample T-test with an alpha = .05 and power = 0.80, and determined that the minimum sample size was 34 individuals (GPower 3.1). Unfortunately, due to not enough volunteers meeting the minimum prerequisites, this number of volunteers was unattainable. All volunteers were given written instructions and watched a six-minute video, made by the author, on how to operate both measuring devices. Additionally, I gave each volunteer written and pictorial instructions on how to conduct the measurements for each of the four bone elements. These instructions directly followed the procedures described in the "Data Collection Procedures For Forensic Skeletal Material 2.0" (Langley et al. 2016). This article was used because of its clear instructions on how to conduct the measurements, and it had all the measurements required for this study. See Appendix 1 for detailed information about how these measurements were conducted.

Bone elements were chosen because they vary in the degree of difficulty involved in collecting osteometric data, including maximum length, from them. The tibia is considered to be difficult to measure due to its morphology (Adams and Byrd 2002). The femur and humerus, in contrast, are not considered to be difficult to measure. Even though the ulna is not considered to be difficult to measure (Adams and Byrd 2002), it does present some difficulty because of its distinct morphology, specifically the olecranon process and distal styloid process. Measurements for each bone element were generated by each volunteer using the PODv1 and PaleoTech osteometric board.

After watching the video, the volunteers independently assembled and operated each device. The only assistance I as the proctor provided was to calibrate the PODv1 and assist those volunteers having technical issues with one of the two devices. The volunteers used both measuring devices to measure all four bone elements during three different rounds. A round was completed by the volunteers using both devices to measure the four different bone elements. This resulted in each volunteer measuring each bone six times for a total of twenty-four measurements per person (Table 5.1).

Table 5.1 The number of measurements from volunteers

DEVICE	HUMERUS	ULNA	FEMUR	TIBIA	TOTAL
PODV1 (1 VOLUNTEER)	3	3	3	3	12
PALEOTECH (1 VOLUNTEER)	3	3	3	3	12
ALL VOLUNTEERS	23	23	23	23	23
TOTAL	138	138	138	138	552

The volunteers recorded their bone length measurements using an Excel spreadsheet. In order to keep this project unbiased and to maintain anonymity each volunteer recorded their measurements, number of years of experience with an osteometric board, and their discipline of study (e.g., anthropology or forensics). No other personal information was recorded.

CHAPTER VI

RESULTS

Even though the minimum number of individuals initially needed for this study was not met, the results remained statistically significant. This statistical significance was due to the volunteers taking three different measurements of each bone element with both devices, which summed to 552 measurements. These measurements gave each bone element 138 independent measurements with 69 on each device. This generated enough data to compare the PODv1 to the Paleo-Tech Lightweight Field Osteometric Board length measurements.

Results for Between Devices

A Wilcoxon rank sum test with continuity correction was used to compare the volunteers' length measurements of the four bone elements taken using the PODv1 and the PaleoTech osteometric board (Wilcoxon 1945). The Wilcoxon rank sum test with continuity is used for these data because the variances of the two independent samples are not equal and they do not have a normal distribution. The length measurements of the tibia ($w = 2367$, p-value = 0.8082) and humerus ($w = 2629.5$, p-value = 0.2824) taken from both devices showed no statistical significance between them. These two results support Ho1a and Ho1b, which states that the volunteers using the PODv1 to measure a tibia and a humerus will not be statistically significant in the length measurements that they generate when compared to the Paleo-Tech Lightweight Field Osteometric Board. However, there was a statistically significant difference between the two devices' length measurements of the femur ($w = 1616.5$, p-value = 0.001025) and ulna (w =

3550.5, p-value = 0.0000003017). These two results support H1, which state that the measurements taken by volunteers using the PODv1 and the Paleo-Tech Lightweight Field Osteometric of a tibia, humerus, femur, and ulna will be statistically significant between the PODv1 and Paleotech Lightweight Field Osteometric Board measurements.

The mean and standard deviation rates were calculated for each of the four bones using both devices (Table 6.1 and Figure 6.1). Neither device means showed a larger or smaller mean length measurement trend. The standard deviation rates did show a trend, with the PODv1 having a larger value than the PaleoTech osteometric board. An exception from this trend was the standard deviation rate for the tibia made by the volunteers using the Paleotech (sd= 16.23). These results support H1, which states that the measurements taken by volunteers using the PODv1 and the Paleo-Tech Lightweight Field Osteometric for a tibia, humerus, femur, and ulna will be statistically significant between the PODv1 and Paleotech Lightweight Field Osteometric Board measurements.

Table 6.1 Mean and standard deviation

	PODv1		PaleoTech	
Bone	**Mean**	**sd**	**Mean**	**sd**
Ulna	260.68	2.422	262.348*	.9483*
Femur	412.55	3.583	411.45	1.235
Tibia	349.51	3.433	350.216*	1.895*
Humerus	336.23	3.158	337.09	1.738

*One outlier removed from the ulna and two from the tibia. The original ulna mean was 291.333 and standard deviation was 240.7311. The original tibia mean was 347.457 and standard deviation was 16.23.

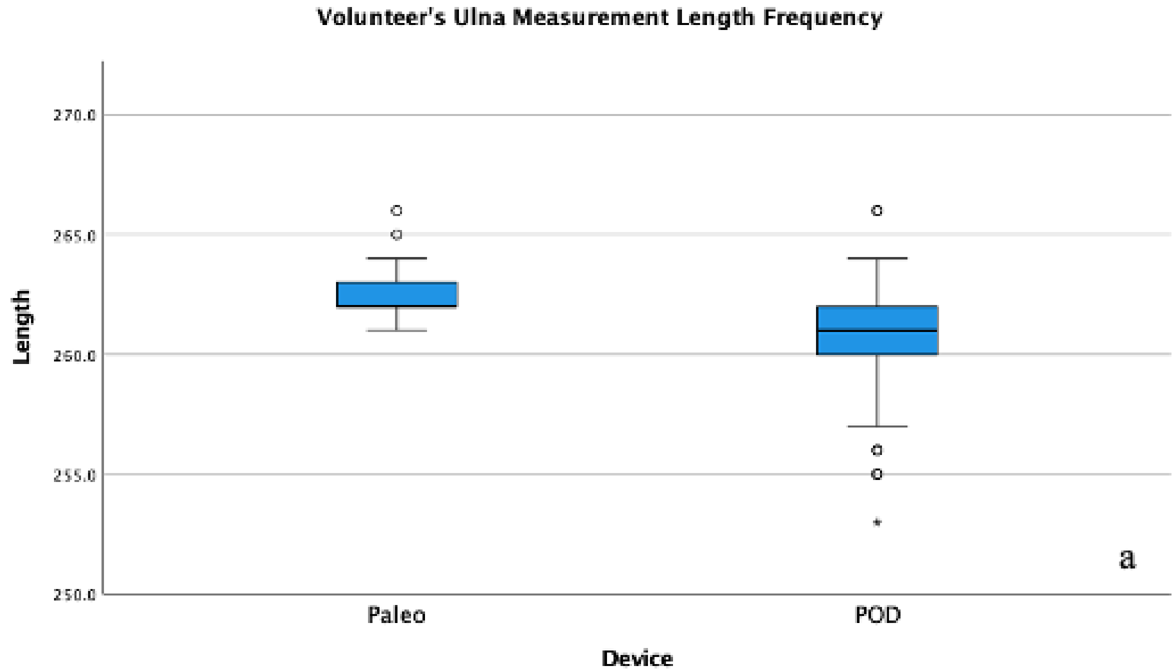

Figure 6.1 Mean and standard deviation for the ulna

This figure shows both devices mean and standard deviation for the ulna (a). One outlier was removed from the ulna PaleoTech measurements. This outlier were removed due being over 50 mm from the baseline.

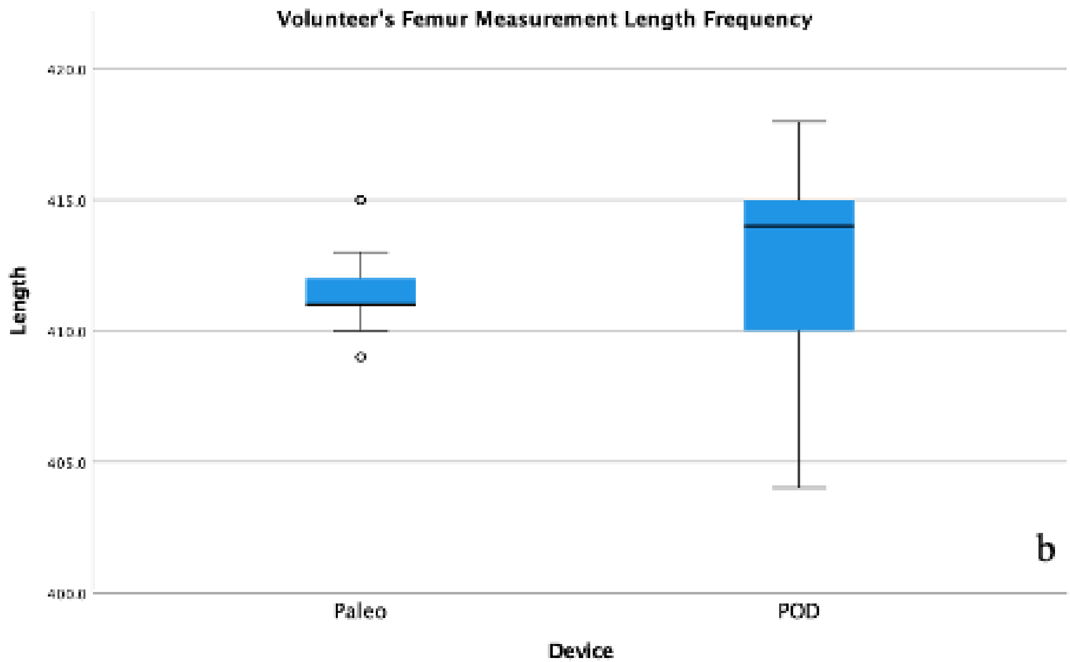

Figure 6.2 Mean and standard deviation for the femur

This figure shows both devices mean and standard deviation for the femur (b).

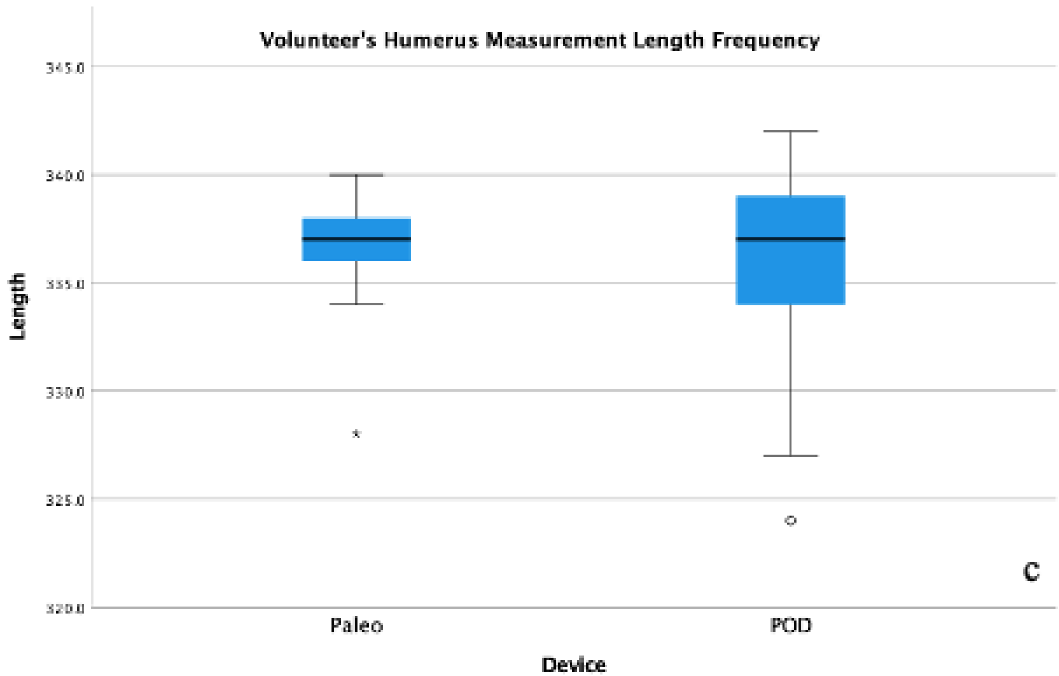

Figure 6.3 Mean and standard deviation for the humerus

This figure shows both devices mean and standard deviation for the humerus (c).

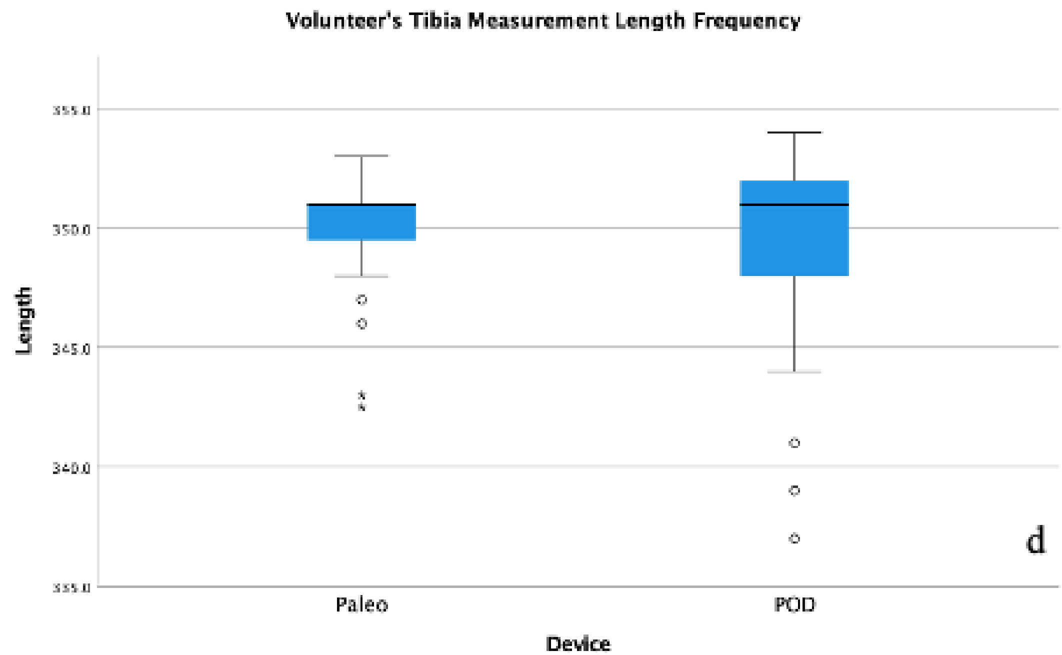

Figure 6.4 Mean and standard deviation

This figure shows both devices mean and standard deviation for the tibia (d). Two outliers removed from the tibia PaleoTech measurements. These outliers were removed due being over 50 mm from the baseline.

The inter-observer percent error rate was calculated for the volunteers using the PODv1 and the PaleoTech osteometric board (Table 5.2). Error percentage rate was calculated using the baseline value (described above) and the total average of all the volunteers’ measurements for each bone element with both devices. These results show that both devices have less than a 2% error rate with each bone element. PaleoTech had an overall lower percent error rate than the PODv1. The only PaleoTech length measurement to have a higher percent error rate than the PODv1 was the tibia. These results support H2, which states that the volunteers using the POD version 1 and the Paleo-Tech Lightweight Field Osteometric Board will have measurements that exhibit an inter-observer error less than 2%, utilizing the measurement of the author as a baseline.

Table 6.2 Error rate for PODv1 and PaleoTech

Precent Error Rate for PODv1 and PaleoTech

Device	Ulna	Tibia	Femur	Humerus
PODv1	0.628 %	0.8213 %	0.3773 %	0.3255 %
PaleoTech	0.0067 % *	1.0259 % *	0.1111 %	0.0720 %

*One outlier removed from the ulna and two from the tibia. The original tibia percent error rate was 10.421 % the original ulna percent error rate was 1.0239%.

Results for Intra-Observer Error

The volunteer's intra-observer error was examined by averaging their standard deviation rate for the three measurements that they conducted for each bone element with both devices (Appendix 3). Both devices showed, overall, low to no variation for each volunteer's three different round measurements. The PaleoTech board did yield measurements lower standard deviation rates, however. The outstanding difference between them was that the PaleoTech had two volunteers score a standard deviation rate higher than 4.5 mm (MSU-1: Humerus - 6.08, Tibia – 51.96/ MSU-9: 57.74) were the PODv1 had none. These results support H1, which states that the measurements taken by volunteers using the PODv1 and the Paleo-Tech Lightweight Field Osteometric for a tibia, humerus, femur, and ulna will be statistically significant between the PODv1 and Paleotech Lightweight Field Osteometric Board measurements.

CHAPTER VII

DICUSSION AND CONCLUSION

The purpose of this study was to test the reliability and validity of the PODv1 against the industry-leading osteometric board, the Paleo-Tech Lightweight Field Osteometric Board, by providing measurements of intra-observer and inter-observer error during the collection of osteometric data. After analyzing the volunteers' measurement data, the results show that the PODv1 is a reliable and valid device for collecting osteometric data, specifically long bone length.

These length measurement results show the PODv1 and PaleoTech osteometric board have no statistical significance between the humerus and tibia. However, these results are the opposite of the femur and ulna that show them being statistically significant between the two measuring devices. So, one 'difficult' and one 'easy'-to-measure bone element had statistically significant differences and one 'difficult' and one 'easy'-to-measure bone element showed no statistical difference between the two devices ('difficult' and 'easy' as defined by Adams and Byrd 2002). The volunteers' unfamiliarity with using the PODv1 and misinterpreting the measurement directions most likely caused these results, discussed further below. The inter-observer error between the long bone measurements of both devices showed that the PODv1 generated a larger standard deviation rate between volunteers compared to the PaleoTech osteometric board. This result is from the PODv1's need for more modifications, discussed further below. Both measuring devices resulted in an inter-observer percent error rate of less than

2% for all bone elements. When measuring long bone measurements, a comparison of the intra-observer error between the PODv1 and the PaleoTech osteometric board showed very little difference. These two results show that both measuring devices fall within the accepted anthropometric standards for measurement errors (Adams and Byrd 2002; Perini et al. 2005). In sum, these results show the PODv1 and the PaleoTech osteometric board are reliable and valid measuring devices but are influenced by a few factors that caused similarities and differences between them. These factors included calibration issues, transcription errors, experience level, and user errors.

Both devices' encountered calibration issues during the volunteers' collection of osteometric data. A software glitch was noticed with the PODv1 in that it would incorrectly calibrate or fall out of calibration during measurement rounds. The incorrect calibration was correctable by conducting a calibration for the device. Even with the PODv1 having a calibration issue, it showed to be a comparable measuring device to the PaleoTech osteometric board. The PaleoTech board's calibration issue was due to the board's design. This design issue is due to the sliding panel not properly securing to the PaleoTech base board, which caused the sliding panel to be loose. The looseness of the panel caused it to shift on the base board, making it possible to have two different length measurements outcomes depending on what side the volunteer was reading the measurement. This loose panel issue may only be a problem with this specific board located at MSU, but it would be a more complicated fix than simply recalibrating the PODv1.

A transcription error was also a contributing factor for the difference between the two devices. Three errors exceeding 50 mm from the mean were only found in the PaleoTech data. These significant transcription errors included two tibia measurements (261 mm, 249 mm) and one ulna measurement (2226 mm). The errors are thought to be caused by the volunteers either misreading the measurement or mistyping their reading. This transcription error issue was not found with the PODv1 data. This difference is thought to be from the PODv1's ability to display a digital length measurement, which is why no significant transcription errors were within its measurements.

Differences in the amount of experience with an osteometric board also caused variation among the volunteers' length measurements. Experience level was categorized into three different groups: Novice, Intermediate, and Expert. The Novice group incorporated those who had less than three years of osteometric board experience (13 volunteers), Intermediate were those with 3 to 10 years (6 volunteers), and Expert were those who had 10 or more years of experience (4 volunteers). Both devices showed a general trend of less deviation as experience level increased (Figure 7.1). The ulna and tibia showed the least deviation among all groups with both devices (Figure 7.1). Between both devices, the PaleoTech osteometric board showed less deviation among each group than the PODv1. The last issue that caused similarities and difference between the two devices was user error of how to conduct the measurements and use each device.

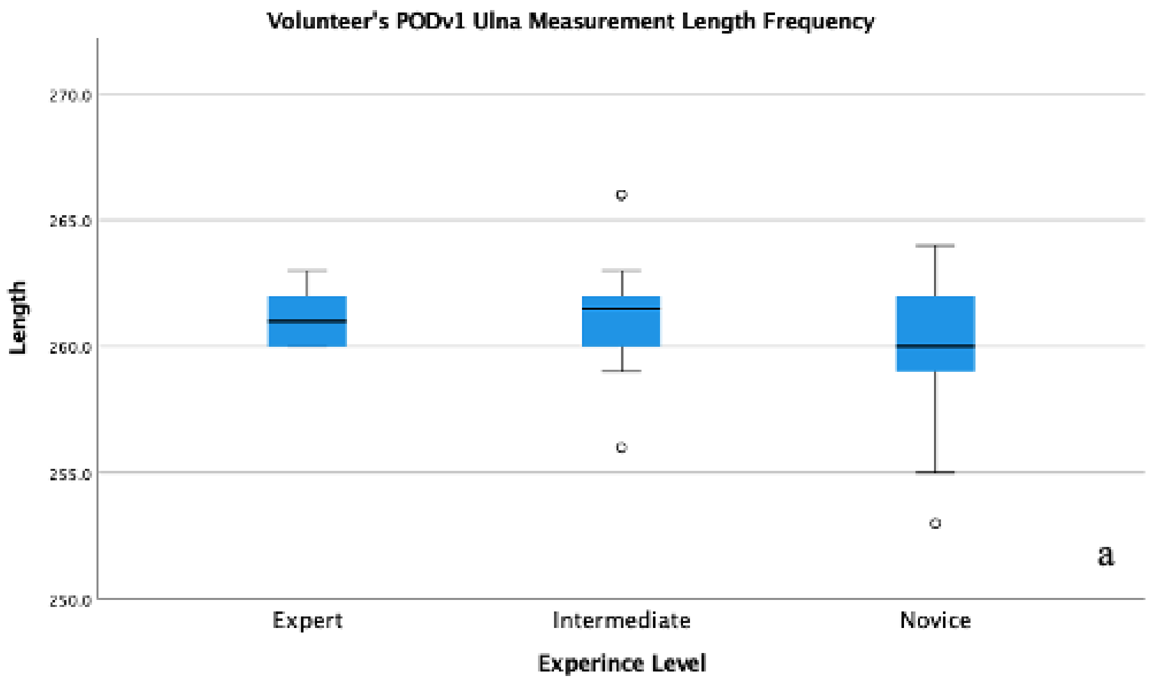

Figure 7.1 Volunteer's PODv1 ulna measurement by experience

This figure shows the PODv1 ulna measurements grouped by experience level categories (a).

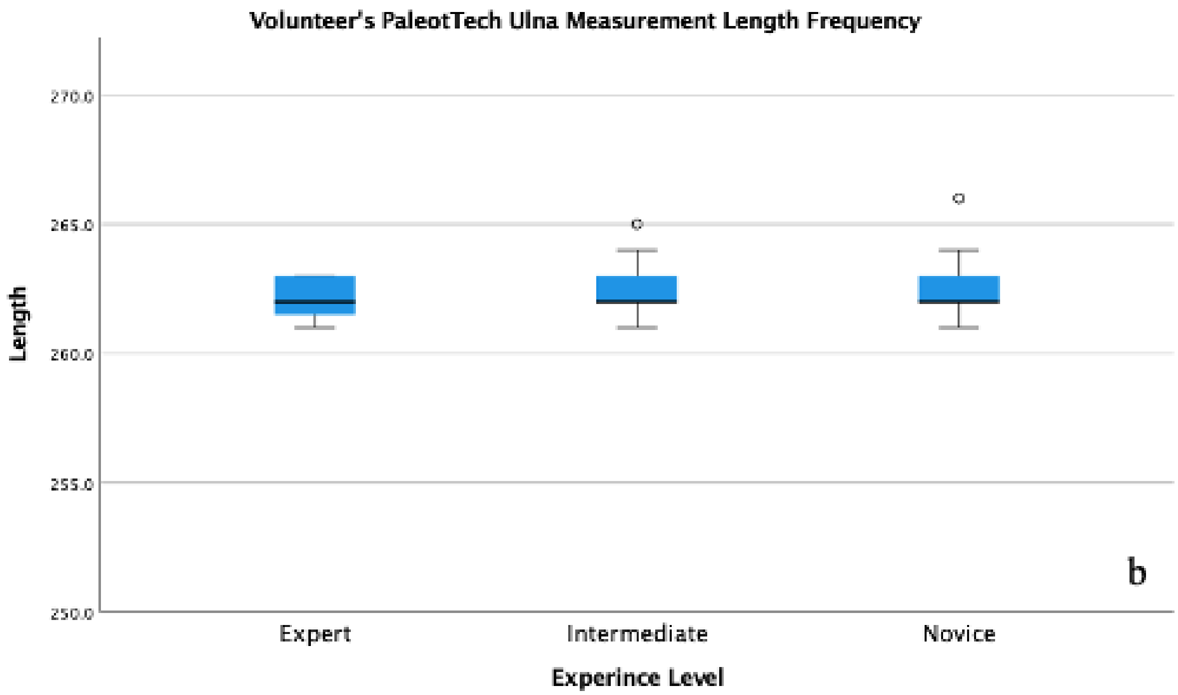

Figure 7.2 Volunteer's ulna measurements by experience

This figure shows the PaleoTech ulna measurements grouped by experience level categories (b). One outlier removed from PaleoTech ulna measurement. This outlier was removed due to being over 50 mm from the baseline.

Misunderstanding how to properly measure each of the four bone elements was a common theme among all volunteers. The volunteers either used the written bone measurement instructions, only the pictures, neither of them, or a combination of the two instructions. These variations are thought to be from volunteers misreading the written instructions, not understanding the instructions, and assuming they know how to conduct the measurements without instructions. An example of this issue was found in the percent error rate from the tibia length measurements made by the PaleoTech (1.0259 %) and PODv1 (0.8213 %) being higher than the other bone element measurements. The higher rate was caused by the volunteers measuring for maximum length rather than the distance from the lateral condyle to the medial malleolus. This caused most of the volunteers' measurements to be longer in length than the baseline. The lower rate with the PODv1 is believed to be caused by the looseness of the Sliding Panel and the placement of the laser, which is discussed further below.

Limitations

The PODv1's use of modern technology to take length measurements may make it a promising candidate for the future replacement of portable osteometry boards but it does raise some questions on its limitations. A significant possible limiting factor is the PODv1 being battery operated. The argument can be made that it will become a paperweight if this device dies, while the current board has no such issue. It is true, that the PODv1 battery could die if it is not charged, but the same problem plagues any other electrical device used by bioarchaeologist or osteologist. As with other electrical devices, charging the PODv1 before use resolves this problem.

Another technological issue with the PODv1 is calibration. If a researcher fails to calibrate the PODv1 before using it, it could create false data, which is not an issue with the PaleoTech osteometric board. Even though the PaleoTech osteometric board does not require calibration, it does not escape the potential issue of creating false data: The loose sliding panel can change the measurements. Researchers can avoid creating false data with both devices by being aware of the PaleoTech problem and adequately calibrating the PODv1.

Looking Forward

The current PODv1 design is still in the testing phase, with some minor improvements needed to make it a candidate for replacing the portable osteometric board design. These changes include adding more stabilization features, changing the laser's position to the top of the device, and fixing the calibration issue.

The misalignment of the PODv1 was a common issue among volunteers, which caused the panels to be slightly crooked. This created increased or decreased measurement lengths. If the PODv1 is misaligned, the sides of the Sliding Panel are the areas that will have the least reliable measurements. This issue is compounded by having the laser placed on the side. Moving the laser to the top and center of the Laser Panel will move the target region to the center of the Sliding Panel, minimizing error due to misalignment of the device (Figure 7.2). Additional refinements will include adding a wider base to the Sliding Panel, more weight to the Sliding Panel, and making the side stabilizers wider for both panels. The calibration issue should be easily rectified with software tweaks to save and maintain calibration.

Figure 7.3 Laser placement update

This figure shows the laser sensor future location (red arrow) and changed target area location (red circle: new target area & blue circle: old target area).

Unlike the current board design, the PODv1 uses modern technology to take measurements, giving it the ability to decrease data collection time. Currently, the PODv1 takes an average of 20 measurements in Precision Mode within a matter of seconds. This feature decreases the time for taking multiple measurements of a single bone element for increased reliability and validity, which would be impossible to complete with the current osteometric board design. For example, if the PODv1 created the baseline in this research, it could take three different Precision Mode measurements, equal to 60 different measurements. This same task using the PaleoTech osteometric board would take an impractical amount of time. Additionally, adding Bluetooth technology to the PODv1 would allow collected data to automatically transfer to an APP. The APP could store all the collected data until the time the researcher uploads it into their data base. This automatic transfer of data would minimize transcription errors and decrease data entry time, which would allow for increased time to analyze the data for research.

Conclusion

The primary research question for this study was "What is the reliability and validity of the PODv1 as a device for collecting osteometric data, specifically long bone length?" This was accomplished by providing measurements of intra-observer and inter-observer error during the collection of osteometric data for the PODv1 and the PaleoTech board. The intra-observer results for the PODv1 and the PaleoTech board showed very little difference between the two devices. Even though, the inter-observer results showed that the PODv1 was statistically comparable to the PaleoTech board and that both devices had less than a 2% error rate, it did have differences between them. These differences included the PODv1 having larger standard deviation rates between volunteers compared to the PaleoTech board and the PODv1 having a tibia percent error rate that was less than the PaleoTech. The differences between the two devices were influenced by calibration issues, transcription errors, experience level, and user errors. After analyzing the volunteers' measurement data, the results show that the PODv1 and the PaleoTech are both reliable and valid device for collecting osteometric data, specifically long bone length. With more testing and modifications, the PODv1 could become the new standard for portable osteometric measuring devices.

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APPENDIX A

MEASUREMENT INFORMATION

Table A.1 Bone measurement descriptions

Bone	Measurement	Description	Source
Humerus 	Maximum Length of the Humerus "The distance from the most superior point on the head of the humerus to the most inferior point on the trochlea."	"Place the humerus on the osteometric board so that its long axis parallels the instrument. Place the head of the humerus against the vertical end board and press the movable upright against the trochlea. Move the bone up, down and sideways to determine the maximum distance."	Measurement #45 (N. Langley et al. 2016, 74) drawing on Hrdlička (1920:126)
Ulna 	Maximum Length of the Ulna "The distance between the most proximal point on the olecranon and the most distal point on the styloid process."	"Place the proximal end of the ulna against the vertical end board. Press the movable upright against the distal end while moving the bone up, down and sideways to obtain the maximum length."	Measurement #54 (N. Langley et al. 2016, 75-76) drawing on Bräuer and Hrdlička (1988 204, #1; 1920:127)

Table A.1(continued)

Femur 	Bicondylar Length of the Femur "The distance from the most proximal point on the head of the femur to a plane drawn between the inferior surfaces of the distal condyles."	"Place the femur on the osteometric board so that the bone is resting on its posterior surface. Press both distal condyles against the vertical end board while applying the movable upright to the head of the femur."	Measurement #76 (N. Langley et al. 2016, 78) drawing on Bräuer and Hrdlička(1988: 216, #2; 1920: 128)
Tibia 	Length of the Tibia "The distance from the superior articular surface of the lateral condyle of the tibia to the tip of the medial malleolus."	"Place the tibia on the osteometric board resting on its posterior surface with the longitudinal axis of the bone parallel to the board (Hrdlička 1920). If using an osteometric board without a hole, place the tibia on the osteometric board so that it the long axis is parallel to the board. The measurement is taken from the lateral condyle to the tip of the medial malleolus."	Measurement #86 (N. Langley et al. 2016, 81) drawing on Bräuer (1988: 220, #1)

The table above gives a description on how the humerus, ulna, femur, and tibia were measured.

APPENDIX B

EQUIPMENT INFORMATION

Table B.1 Equipment descriptions

Equipment	Description	Technical Specifications
Portable Osteometric Device Version 2 (PODv1) 	This model consists of two main components that are the Laser Panel and Sliding Panel. The Laser Panel attaches to a table using a clamp and the Sliding used to sandwich the bone that is wanted to be measured. The P.O.D. uses an internal laser sensor that uses time-of-flight technology to measure the distance between the two panels. It has two different measuring options that are displayed on an LCD screen: Live Measure and Precision Mode. The Live Measure displays a constant maximum length, 25%, midpoint, and 75% of the distance. Precision Mode takes the average of 20 measurements and displays it on the LCD screen.	Dimensions – (Stacked)-115mm x 100mm x 58 mm (Laser Panel)-115mm x 100mm x 32mm (Sliding Panel)-115mm x 100mm x 25mm Weight- .813 lbs Range – 30mm - 40m Power - Rechargeable batteries (120 hrs.)
Paleo-Tech Lightweight Field Osteometric Board 	This Osteometric board is a portable version of the original design that folds up and is meant to be easier to transport. It uses a guided Sliding Panel to manual record measurements.	Dimensions – (Assembled) - 600 x 165.1 x 12.7 mm (Folded) -304.8 x 165.1 x 38.1 mm Weight- 2.7 lbs Range –1 mm – 600 mm Power - None

The table above lists and describes all the equipment that were used.

APPENDIX C

VOLUNTEER’S STANDARD DIVIATION RESULTS

Table C.1 PODv1 standard deviation results.

PODv1 Standard Deviation Results				
Volunteer	Humerus	Tibia	Femur	Ulna
MSU-1	0.57735027	1.15470054	1.52752523	2.64575131
MSU-2	1.15470054	0.57735027	2.30940108	0.57735027
MSU-3	0	1	0.57735027	0.57735027
MSU-4	2	1.52752523	1.52752523	0.57735027
MSU-5	3.05505046	2.51661148	1	1.73205081
MSU-6	2.081666	1	0.57735027	1.15470054
MSU-7	1	1.15470054	1.15470054	2.081666
MSU-8	1.15470054	0.57735027	1.15470054	2.30940108
MSU-9	0	1.73205081	0.57735027	3
MSU-10	0.57735027	0	0	1.15470054
MSU-11	1.52752523	0	1	0.57735027
MSU-12	0.57735027	1.15470054	0.57735027	2.081666
MSU-13	0.57735027	0.57735027	1.52752523	0
MSU-14	0.57735027	1.15470054	0.57735027	0.57735027
MSU-15	2.081666	0.57735027	1.15470054	0
MSU-16	3.21455025	1.73205081	2.64575131	1.73205081
MSU-17	1.15470054	1.15470054	0.57735027	0.57735027
MSU-18	0.57735027	0.57735027	3.7859389	0
MSU-19	1	1.15470054	0.57735027	0.57735027
MSU-20	0.57735027	0.57735027	1	0.57735027
MSU-21	4.04145188	2	0.57735027	1.15470054
MSU-22	1.52752523	1	1	0.57735027
MSU-23	1	1	1.15470054	0.57735027

The table above lists the volunteer’s standard deviation results for the PODV1

Table C.2 Paleo-Tech Lightweight Field Osteometric Board standard deviation results

PaleoTech Standard Deviation Results				
Volunteer	Humerus	Tibia	Femur	Ulna
MSU-1	6.08276253	51.9615242	1	0
MSU-2	1.73205081	0	1.52752523	1.15470054
MSU-3	0.57735027	1	1.15470054	2
MSU-4	0.57735027	0	0.57735027	0.57735027
MSU-5	0.57735027	0	0.57735027	1
MSU-6	0.57735027	0	0	0
MSU-7	0	0.57735027	1.15470054	0
MSU-8	0	1	0.57735027	1.15470054
MSU-9	0	57.7436865	0	0.57735027
MSU-10	0.57735027	0.57735027	0	0.57735027
MSU-11	0.57735027	1.15470054	0.57735027	1
MSU-12	0.57735027	1	0.57735027	0
MSU-13	0	0	0.57735027	0
MSU-14	0	0	1	0.57735027
MSU-15	0	1	0	0.57735027
MSU-16	0	0	0	0.57735027
MSU-17	1.15470054	0	1.15470054	0.57735027
MSU-18	0.57735027	0	0.57735027	0
MSU-19	0.57735027	0.57735027	1.52752523	0.57735027
MSU-20	0.57735027	1.73205081	0.57735027	0
MSU-21	0	1.89296945	0.28867513	0.28867513
MSU-22	0.57735027	0	0.57735027	0
MSU-23	0.57735027	0	0	0

The table above lists the volunteer's standard deviation results for the Paleo-Tech Lightweight Field Osteometric Board.