**Using the shape of the basicranial portion of the temporal bone to distinguish between relatively closely-related human populations**

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*ABSTRACT*

Cranial morphology is routinely used in archaeology to identify population affinity in human skeletal remains and the shape of the basicranial portion of the temporal bone, in particular, has been shown to have a strong phylogenetic signal. Because the morphology of this section of the temporal bone has been found to have one of the strongest phylogenetic signals in the crania, it can be effectively used to distinguish between populations on a large, often global, scale. However, its applicability to the analysis of relatively closely-related groups remains largely unexplored. The retention of population signatures in the shape of this small portion of the temporal bone is particularly useful for archaeology as often its fragility makes analysis of the full cranium unlikely. In addition, if the shape of the basicranial portion of the temporal bone can identify differences between relatively closely-related populations with similar accuracy as it does for more distantly-related populations, this would significantly aid analyses of population history on a local scale. To test this, we initiated a study that used three-dimensional geometric morphometrics to investigate the shape variation of the temporal bone of two British archaeological populations that were separated both temporally and geographically. The results of a MANOVA found statistically significant shape differences between the two populations and a DFA found that the shape of the temporal bone can correctly classify 84.7% of individuals into their respective population. Therefore, the findings of this study suggest that the shape of the temporal bone can accurately identify differences between two relatively closely-related populations. Future research needs to focus on examining larger samples from a greater number of populations to determine whether this pattern is widespread.

**Keywords: Human variation, cranial shape, shape analyses, relatedness, identification, Poundbury, Portmahomack**

**INTRODUCTION**

Identifying population affinity in human skeletal remains is an important endeavour in both bioarchaeology and forensic anthropology, as it can shed light on population history, human migrations, and human dispersals (Howells, 1989; Roseman, 2004; Relethford, 2004; Harvati & Weaver, 2006a,b; Gunz *et al*., 2009; Spradley & Jantz, 2016). In recent years there have been major advances in DNA methodology that have facilitated research into the ancestral background of human skeletons from different populations (Patterson *et al.*, 2012; Mathieson & McVean, 2014; Novembre & Peter, 2016). However, not only are these methods expensive and sometimes difficult to perform on aDNA due to its fragility (Hoss *et al*., 1996), but most DNA databases are based on the genetic makeup of modern population groups (e.g. International HapMap Consortium, 2003; The 1000 Genomes Project Consortium, 2012), limiting their ability to identify ancestry in archaeological remains (Morozova *et al*., 2016). Alternatively, cranial shape has been suggested to have significant concordance with phylogenetic distances, making the analyses of morphological differences between populations a relatively cost-effective alternative for investigating the ancestral background of skeletal material (Roseman, 2004; Reyes-Centeno *et al*., 2017).

Many studies have so far used either traditional linear metrics or geometric morphometrics to investigate the relationship between cranial shape variation and population affinity in a large number of modern and archaeological populations (Howells, 1973; Hennesy & Stringer, 2002; Viðarsdóttir *et al*., 2002; Roseman, 2004; Harvati & Weaver, 2006a,b; Perez et al., 2007; Perez & Monteiro, 2009; Smith *et al*., 2013). Traditional metrics have largely been replaced in analyses of morphological shape, as the data consists of lengths, angles and widths, providing little information about the overall geometry of the crania (Slice, 2007). Population-specific cranial shape traits are established very early in ontogeny and these traits are accentuated throughout development (Viðarsdóttir *et al*., 2002: Smith *et al*., 2013), however the extent to which these indicators are expressed varies according to the cranial area. Many cranial elements are developmentally flexible and vulnerable to epigenetic interactions with the environment (Harvati & Weaver, 2006a). For example, the facial skeleton has been found to be considerably reflective of climatic variables (Roseman, 2004; Hubbe *et al*., 2009), especially in areas linked to the nasal aperture which varies dramatically according to humidity, latitude, and temperature (Carey & Steegmann,1981; Franciscus & Long, 1991). Diet, through mastication of various foods, has also been found to influence cranial shape by exerting mechanical strain on the cranium (Collard & Wood, 2007; von Cramon-Taubadel, 2009). However, the shape of the cranial vault, including the temporal bone, has been found to be largely unaffected by such environmental factors, generally correlating with phylogenetics through morphological signatures of population history (Olson, 1981; Wood & Lieberman, 2001; von Cramon Taubadel 2009, 2011).

The conservation of population affiliation in the morphology of the cranial vault when compared with other cranial areas, has also been confirmed through a number of geometric morphometric studies (Howells, 1989; Roseman, 2004; Harvati & Weaver, 2006b; Smith *et al*., 2013). For example, Harvati and Weaver (2006a) found that both the temporal bone and other bones of the cranial vault were indicative of population affinity in ten recent human populations. To further explore this finding, Harvati and Weaver (2006b) added three more sample populations (13 groups) and investigated the relationship between the anatomical shape of three cranial areas (face, neurocranium and basicranial portion of the temporal bone) with neutral genetic distances and climatic variables. Their findings were similar to previous studies (Carey & Steegmann,1981; Franciscus & Long, 1991), that indicated that whilst the shape of the facial skeleton mostly reflects climatic variables, the temporal bone and neurocranium significantly correlate with neutral genetic distances (Harvati & Weaver, 2006b). In their sample, the temporal bone was shown to be more conservative of population signatures than the shape of the complete cranium (Harvati & Weaver, 2006b). In particular, they found that the cranial vault was more effective for identifying relationships in populations that have diverged relatively recently whilst the temporal bone is indicative of considerably earlier divergences in prehistory between sub-Saharan African and non-sub-Saharan African populations.

Although the findings of these studies support the use of cranial shape variation to determine population affinity, there are a few limitations to these previous works that may be important for using it in archaeological research. First, Harvati and Weaver (2006a,b) found that temporal and vault shape can distinguish between distantly related populations; for example, one population from sub-Saharan Africa and one from Northern Europe. And although important, their findings do not provide information about whether the shape of the cranial vault or temporal bone can be used to distinguish relatively closely related populations, such as two British populations that are separated by geography or time. Second, the use of other bones of the cranial vault to distinguish populations (Harvati and Weaver 2006; von Cramon Taubadel 2009, 2011) may have limited application to archaeological contexts, as the parietals, frontals, and occipital can be fragile and often fragmented, precluding analysis of the full cranium. Traditional metrics have found to be very effective at determining between closely related populations. For example, Ousley et al. (2009) found that Northern and Southern Japanese individuals from Howells (1973) cranial dataset could be identified to 89% accuracy, however analyses such as this include measurements taken of the full cranium, which is often not possible in archaeological situations. If a smaller section of the cranium, such as the basicranial element of the temporal bone, is found to be effective at distinguishing between closely related populations, this would be more useful for archaeology and forensic anthropology.

With these issues in mind, we initiated a study that aimed to test whether the shape of the temporal bone reflects intergroup variation between relatively closely related populations. To accomplish this, we used 3D geometric morphometrics to investigate the shape variation of the temporal bone of adult individuals from two archaeological sites, Portmahomack, an Early Medieval monastery from Scotland, and Poundbury, a Romano British site from London. The populations are both British in origin and thus relatively low amounts of shape difference are expected compared to the worldwide populations in Harvati and Weaver (2016), since population groups that share common ancestry or inhabit a similar environment should have similar morphologies (Roseman, 2004). We have selected basicranial landmarks for analyses based on those of Harvati and Weaver (2006b) in order to attempt to accurately identify morphological variation that reflects inter-group differences between phylogenetically similar archaeological populations. We hypothesize that the shape of the temporal bone will be able to distinguish between the two populations and if supported, these findings will be of importance for both archaeological research and forensic anthropology.

**MATERIALS AND METHODS**

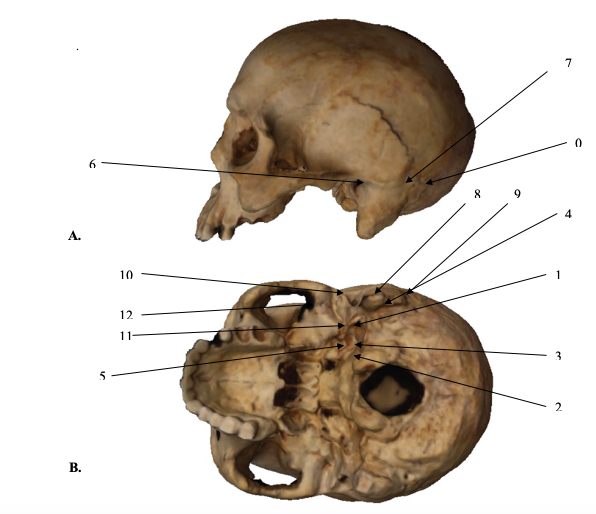
The sample consisted of a total of 38 adult individuals from two English archaeological populations, with 19 individuals being from Portmahomack in Scotland and 19 being from and Poundbury in Dorchester. The material from both sites date to the first millennia AD, the individuals from Portmahomack dating to between 550-800 AD and those from Poundbury to the fourth century AD. Each cranium was selected for analysis based on the overall good preservation of the basicranial portion of the temporal bone. We chose to include only adult male individuals to avoid morphological variation associated with sexual dimorphism. Three-dimensional scans of each crania were created using photogrammetry, which involved the construction of 3D images from 2D photographs (Evin et al. 2016) The scans were created using Agisoft Photoscan©(Agisoft, 2018).

Thirteen homologous anatomical points were selected as landmarks based on those used in Harvati and Weaver (2006b) (Figure 1) and captured on each crania using Landmark Editor© (Wiley 2006). Four individuals did not exhibit an intact mastoid process (1 from Portmahomack and 3 from Poundbury) and were therefore omitted from the main analyses. A secondary analysis was conducted with the inclusion of these specimens without the landmark located on the mastoid process to test the strength of identifying populations without it. For clarity, the analyses on the dataset that included all 13 landmarks will be called Analysis 1 and those performed on the dataset that included only 12 landmarks will be called Analysis 2. A single author (LT) digitized each individual to eliminate inter-observer error. Intra-observer error of landmark digitization was tested through repeat measurements (O’Higgins & Jones, 1998). To assess measurement error, we digitized a single cranium 6 times. The largest Procrustes distance between the repeated observations was compared to the smallest Procrustes distance between the non-repeated observations. The distance between the repeated observations was two times smaller than that between the non-repeated observations (Neubauer et al., 2009), thus we determined that intra-observer error would be unlikely to result in misclassifying individuals into populations.

Once the raw landmark data were acquired, the data were subjected to generalised Procrustes analysis (GPA), which removed rotational, translational, and scaling variation in the landmark configurations (Webster & Sheets, 2010; Slice, 2007; Klingenberg, 2016).The superimposed data were then analysed using principal components analysis (PCA) to assess the morphological variance between the two populations (Bookstein, 1991). In order to reduce noise present in higher components, only the PCs that accounted for 5% or more of the total shape variance were retained for analyses (Zelditch et al., 2005; Balyac & Frieb 2005). Next, we performed discriminant function analysis (DFA) with leave-one-out cross validation to evaluate how accurately the individuals can be assigned to their population based on shape variables (Klingenberg, 2016; White & Ruttenberg, 2007). And lastly, MANOVAs were run to determine the statistical significance of the shape differences between the populations. The GPA, PCA and DFA were performed in MorphoJ© (Klingenberg, 2016) and the MANOVAs were carried out in SPSS 16.0 (SPSS Inc, 2016).

To test for allometry (shape differences deriving from variation in size), a regression of log centroid size against the Procrustes coordinates was performed in MorphoJ© (Klingenberg, 2016). The regression found only 5.62% of the total variation in the shape data was able to be predicted by differences in size, therefore cranial shape is determined to have a strong underlying genetic component in the sample, as opposed being primarily the result of allometric consequences.

Table 1. Anatomical points of the landmarks based on those chosen by Harvati & Weaver (2006).



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| Landmark number | Anatomical point |
| 1 | Asterion |
| 2 | Base of styloid process |
| 3 | Most medial point of the jugular fossa |
| 4 | Most lateral point of the jugular fossa |
| 5 | Proximal origin of the juxtamastoid crest |
| 6 | Carotid canal |
| 7 | Auriculare |
| 8 | Parietal notch |
| 9 | Tip of mastoid process |
| 10 | Distal point on the juxtamastoid crest |
| 11 | Deepest point of lateral margin of the articular eminence |
| 12 | Most inferior point on the the entoglenoid process |
| 13 | Suture between the temporal and zygomatic bones on the inferior aspect of the zygomatic process |

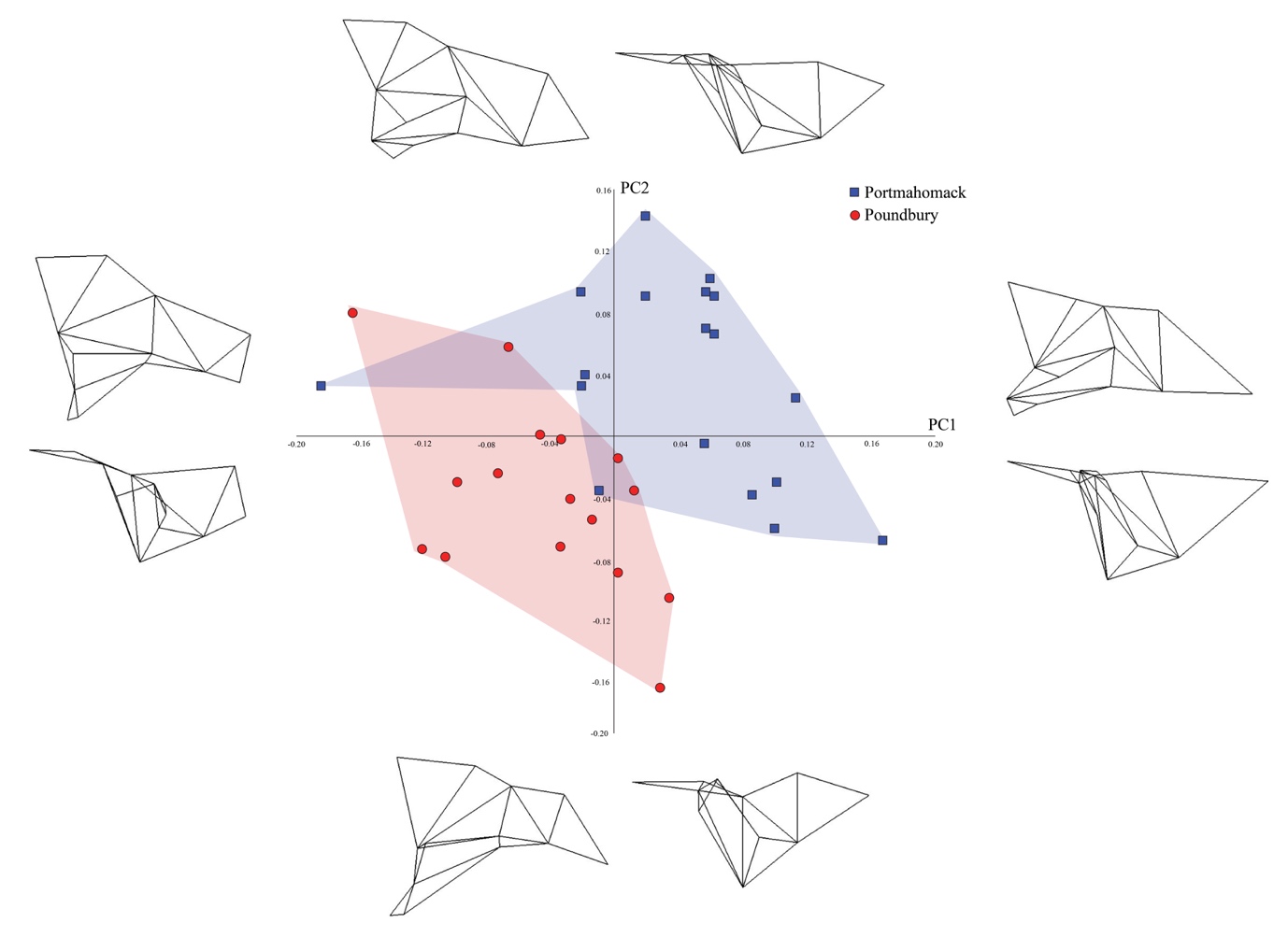
Figure 1. Landmarks used in the analysis based on Harvati & Weaver (2006). A) Lateral view of the cranium. B) Inferior view of the cranium

**RESULTS**

*Analysis 1*

Seven PCs, accounting for 5% or more of the total shape variation, described a total of 77.6% of the shape variance. The cross-validated DFA found a mean accuracy rate of 84.7% of correctly classifying individuals into their population groups (Poundbury = 75% accuracy, Portmahomack = 94.4%), based on the seven retained PCs. This suggests that Portmahomack individuals are more homogenous than Poundbury individuals. The results of the MANOVA found that the differences in temporal shape between two populations was statistically significant (λ 0.116, F=28.424, p<0.0001).

Figure 2 depicts the PCA scatter-plot when PC1, which accounts for 19.2% of the total shape variation, is plotted against PC2, which accounts for 15.5%. Overall, Poundbury individuals score negatively on PC1and PC2, while Portmahomack individuals score more positively. The wireframes illustrate that the main shape difference between the populations is the relative location of the asterion and projection of the mastoid process. In particular, when compared to individuals from Portmahomack, Poundbury individuals tend to exhibit relatively taller, medially translated mastoid processes, more dorsally and superiorly located asterions, and relatively longer and narrower petrous pyramids.



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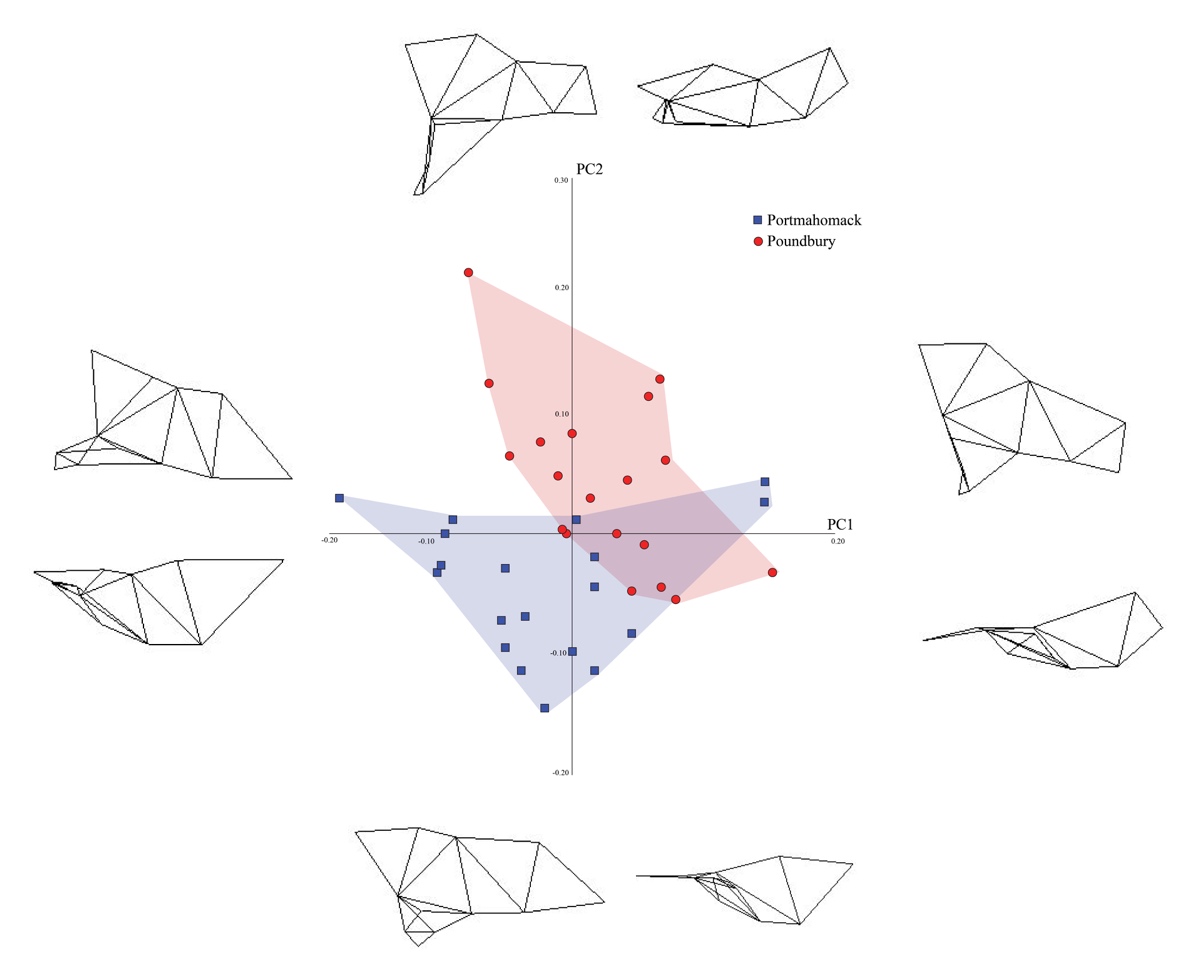
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Figure 2. A PCA scatter plot highlighting the shape differences between Portmahomack and Poundbury along PC1 and PC2. This chart accounts for 19.2% of the total variation in the sample. Wireframes at the end of each PC axis demonstrate the visible shape differences with the top image representing an inferior view of the basicranium and the bottom image representing a lateral view.

*Analysis 2*

For the analysis on only 12 landmarks, the first seven PCs were found to account for 5% or more of the total shape variance, for a combined total of 78.1%. The DFA found that individuals can be correctly classified to  population with a mean accuracy of 65.7% (Poundbury = 57.8% accuracy, Portmahomack = 73.6%). The classification bias revealed in Analysis 1 is mirrored in Analysis 2, with Poundbury individuals showing more heterogeneity than Portmahomack. The MANOVA found that the differences between the populations was statistically significant (λ 0.336, F=8.462, p<0.0001)**.** Figure 3 illustrates the shape differences accounted for on PC1 and PC2 through wireframe deformations. The main shape differences between the two populations are similar to those identified in Figure 2, but without the differences associated with the mastoid process. Additionally, Poundbury individuals tend to have more inferiorly located styloid processes and juxtamastoid crests than those from Portmahomack.



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Figure 3. PC1 (x axis) and PC2 (y axis) charts the shape variance for both populations. Red circles represent Poundbury and blue circles represent Portmahomack. This chart accounts for 36.368% of the total variance. Wireframes at the end of each PC axis demonstrate the visible shape differences with the top image representing an inferior view of the basicranium and the bottom image representing a lateral view.

**DISCUSSION AND CONCLUSIONS**

This study aimed to test whether the shape of the basicranial portion of the temporal bone can accurately distinguish between the crania of relatively closely-related human populations. The results of our first analysis indicate that the shape of the basicranium was indeed effective in distinguishing between individuals from Portmahomack and Poundbury, as the MANOVA found statistically significant differences between the populations. Additionally, we found that the shape of the temporal bone can accurately determine population affiliation, with 84.7% of individuals being correctly classified into population based on a cross-validated DFA. Therefore, our study not only supports the findings of Harvati and Weaver (2006b), but it also indicates that the shape of the temporal bone may be able to accurately identify population-level differences between relatively closely-related populations.

In addition, the results of Analysis 2 are also important, as they indicate that even when the temporal bone is damaged and the mastoid process is missing, the differences between the populations are statistically significant. However, a lower 65.7% rate of correctly classifying individuals into their population group was recorded for Analysis 2. This suggests that damaged or corroded crania have the potential to produce results that distinguish between closely-related populations with a lower level of accuracy. Since the accuracy did change from Analysis 1 to Analysis 2, the findings suggest that the height of the mastoid process is particularly useful for identifying population differences and should be included in landmark configurations when possible. This result might also suggest that the shape of the temporal bone is less differentiated, and it is the inclusion of the mastoid process into the landmark configuration that is significantly influencing the results. Preservation biases and limitations in the archaeological record usually render missing landmarks unavoidable; however, if the mastoid process is well-preserved then it should be included in order to improve the accuracy of identifying population differences with the temporal bone, as suggested by the results of Analysis 2.

The findings have significance for both archaeological and forensic research, as they indicate that a small portion of the cranium, the temporal bone, can be used to accurately determine population affinity. Therefore, the shape of the temporal bone may be particularly useful in this regard and could become part of a standardized method for future archaeological and anthropological research aiming to identify morphological differences between population groups, if a large open-access database of crania is made available. Considering that only a relatively small fragment of the crania can be used to produce this landmark configuration for GM analyses, these findings are particularly useful in archaeological or forensic situations.

Whilst temporal bone shape was found to be an accurate method of distinguishing morphological differences between populations, there are limitations to what these results can reveal for archaeological research. First, the sample size in this study was small and included only two populations, and therefore the results may not be representative, as small sample sizes are more likely to produce classification errors (Raudys & Jain, 1991). In this sense, the small sample size may reflect a trend produced by morphological biases in the specimens as opposed to reflecting a trend present in the whole population. The results of this project however could provide the foundation for larger studies which should incorporate more individuals from multiple populations. In addition to this, future research could look at both sexes (as the current study only examined males) to test the effect of sexual dimorphism on the accuracy of this study. Further studies may also want to build upon this project by testing the effect of individual landmarks on the accuracy of population group determination. This paper looked specifically at the temporal bone and found that the mastoid process slightly affected the accuracy of the results due to preservation biases. It might therefore be of interest to see whether any other of Harvati and Weaver’s (2006b) landmarks have a similar effect. It may be useful to archaeologists and forensic anthropologists to find the minimum number of landmarks that can be used to identify population differences in the temporal bone, as differences in preservation in skeletal remains may produce slight partiality between samples. In addition, whilst this study found evidence to suggest that the temporal bone can be used to accurately distinguish between more closely-related populations than those that have diverged deep in prehistory, there is currently no independent genetic data that confirms how closely related the groups in the study are. Further research should look at replicating the results on genetically known closely-related populations. Overall, despite these limitations, the results of this project support the use of basicranial shape to identify population differences between relatively closely-related populations

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