Did intended firing method condition the morphology of Caddo bottles?

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Color is afforded primacy in ceramic production inquiries, as it provides evidence linked with use, raw material variability, and method of firing. This study is focused on the latter, and asks whether Caddo potters conditioned the morphology of bottles based on the method by which they intended to fire them. Thirty three-dimensional (3D) scans of Hickory Engraved and Smithport Plain bottles were collected from five museums and repositories, and provide 360-degree coverage of exterior colors associated with each vessel. Texture (color) files were used in a quantitative analysis of color where vessels were subsequently binned into two groups based on firing method; oxidized and reduced. The 3D meshes were then analyzed using the tools of geometric morphometrics to assess whether bottle shape and size differ by method of firing. Results demonstrate significant differences in both color and bottle shape—but not size—by firing method. Thus, Formative/Early Caddo potters conditioned the shape of Hickory Engraved and Smithport Plain bottles based upon their intended firing method. This finding provides evidence for two discrete, contemporary, and sympatric Caddo potting communities delimited by macroscopic production attributes, advancing our understanding of Caddo decision-making behaviors related to Formative/Early bottle production.

***Keywords: NAGPRA; American Southeast; Caddo; ceramic; pottery; 3D; computational archaeology; museum studies; digital humanities; non-Western art history; STEM; STEAM***

METHODS

Each of the 30 vessels was scanned (3D) using a Creaform GoSCAN20 to capture color and geometry. Following data collection, each was exported as an .obj file, which includes a bitmap image of the surface color for the entire vessel. Images were subsequently transferred to a transparent background in Photoshop in preparation for analysis using the colordistance package in R (R Core Development Team 2023; Weller and Westneat 2019). Upper and lower limits of the color range were determined based on colors present in the sample. Ten thousand randomly selected pixels were plotted from each image, a histogram binning method was used to group similar colors for each specimen, and pairwise distances between histograms were computed using earth mover’s distance (Rubner and Tomasi 2001; Weller and Westneat 2019) (Figure 2).

**Figure 2. Color binning process for a single object; adapted from Weller and Westneat (2019:Figure 2). In a, image of a Smithport Plain bottle with a transparent background; b, 3D scatterplot of 10,000 non-background pixels in RGB color space; c, clusters from histogram displayed in RGB color space; and d, histogram showing the proportion of non-background pixels assigned to each bin.**

Bottles were coded as ColorGroup A (reduced) and ColorGroup B (oxidized) using the output from a neighbor-joining tree calculated using the color distance matrix. To test whether vessels differ in color according to ColorGroup assignment, the color distance matrix was exported and joined with categorical data. Those data were used in a permutational multivariate analysis of variance in the vegan package to evaluate whether vessel color differs by firing method (*permutations: 10,000; Rsq: 0.55; Pr(>F): 9.999e-05*).

*Geography*

Coordinate data were subsequently harvested and added to the categorical dataset, and all data were imported to a GIS for a distribution analysis to identify core production areas. The GIS environment was modified to ensure that both distributions (oxidized and reduced) would share the same extent, defined by the distribution of all sites in the sample. The distribution of sites serves as a proxy for the distribution of the two types (Hickory Engraved and Smithport Plain) (Figure 1), where a minimum convex polygon could be fitted to those data as a means of delimiting their utilization distribution. Within the utilization distribution (sensu Worton 1989), core production areas were defined using kernel density, where raster values from the location of each site were exported to identify the 50 and 75 percent quantiles. Each raster was reclassified using three classifications; the darkest indicating the 50 percent quantile, another at 75, and a third that holds the remainder (Figure 3).

**Figure 3. Kernel densities representing the 50 (black) and 75 percent (gray) quantiles for reduced bottles, and the 50 (dark brown) and 75 percent (light brown) quantiles for the oxidized bottles.**

Results demonstrate a single core area related to the production of reduced bottles; however, oxidized bottle production occurred across two core areas (one north; the other south). All core production areas occur in the Red River Basin within the known boundary of the ancestral Caddo region.

*Morphology*

The 3D scans of each vessel were imported to Geomagic Design X, where each was landmarked following established and replicable protocols (Selden Jr. 2018a, 2018b, 2019, 2021). Landmark data were aligned to a global coordinate system (Bookstein et al. 1999; Gunz et al. 2005; Kendall 1981, 1984), achieved through generalized Procrustes superimposition (Bookstein 1986; Rohlf 1999; Rohlf and Slice 1990) in R using the geomorph and RRPP packages (Adams and Collyer 2015; Adams and Otárola-Castillo 2013; Baken et al. 2021; Collyer and Adams 2018). Procrustes superimposition translates and rotates the coordinate data to allow for comparisons among objects, while also scaling each biface using unit-centroid size—the square root of the sum of squared distances from each landmark to the specimen’s centroid (Chapman 1990; Dryden and Mardia 1998; Gower 1975; Rohlf and Slice 1990). The geomorph package uses a partial Procrustes superimposition that projects the aligned specimens into tangent space subsequent to alignment in preparation for the use of multivariate methods that assume linear space (Dryden and Mardia 1993; Kent and Mardia 2001; Rohlf 1999; Slice 2001).

Principal components analysis (Jolliffe 2002) was used to visualize shape variation among the Hickory Engraved and Smithport Plain bottles, and the scatterplot represents the dispersion of shapes in tangent space (Figure 3, bottom) (Adams et al. 2013; Bookstein 1991; O'Higgins and Jones 1998; Rohlf and Marcus 1993). To assess whether bottle shape and size differed by type and raw material color group, Procrustes ANOVAs (Goodall 1991) were run that enlist effect-sizes (zscores) computed as standard deviates of the generated sampling distributions (Collyer et al. 2015). A residual randomization permutation procedure (RRPP; n = 10,000 permutations) was used for all Procrustes ANOVAs (Adams and Collyer 2015; Collyer and Adams 2018). Results demonstrate a significant difference in size—but not shape—by type (*RRPP: 10,000; Rsq: 0.14223; Pr(>F): 0.0373*) where the Hickory Engraved bottles were found to be larger than the Smithport Plain bottles. In the analysis of bottle morphology by firing method, vessels were found to differ in shape (*RRPP: 10,000; Rsq: 0.11456; Pr(>F): 0.0275*), but not size (*RRPP: 10,000; Rsq: 0.00224; Pr(>F): 0.8008*).

DISCUSSION AND CONCLUSION

This study used a quantitative analysis of 3D vessel color to demarcate oxidized and reduced Hickory Engraved and Smithport Plain bottles, demonstrating a methodologically rigorous and reproducible approach to categorizing continuous variables associated with color. Bottles in each group were found to differ in shape, but not size, and while the oxidized vessels were produced in two core areas, reduced vessels were produced in one. Thus, Formative/Early Caddo potters conditioned the shape of Hickory Engraved and Smithport Plain bottles based upon the method by which they intended to fire them.

This finding provides evidence for two discrete, contemporary, and sympatric Caddo potting communities delimited by macroscopic production attributes, and is the first to posit differential production intention among Caddo potters. While spatial overlap occurs between the oxidized and reduced core production areas in the north, the southern core production area is geographically isolated. This then begs the question of whether extant morphological differences are apparent between the two core production areas associated with oxidized bottles. While beyond the purview of the current study, others have demonstrated that differences exist between ceramics (Selden Jr. 2018a, 2018b, 2019, 2021), bifaces (Selden Jr. et al. 2020; Selden Jr. et al. 2018), and arrow points (Selden Jr. 2023; Selden Jr. and Dockall 2023; Selden Jr. et al. 2021) recovered from the northern and southern Caddo behavioral regions. Thus, while further study is warranted, should a morphological difference exist between the northern and southern core production areas for oxidized bottles, this would not come as a surprise.

While ancillary to the primary research question, a morphological comparison of Hickory Engraved and Smithport Plain bottles was included in this analysis. Similarities in shape between the two types are known—and demonstrated here—however, what was not known is that Hickory Engraved bottles are significantly larger. This difference in volume may translate to a difference in the ways in which these two bottle types were used by the Caddo. To date, no residue studies have endeavored to identify what specific bottle types were meant to stow.

\*\* look into Caddo funerary rites—what was included in bottles?

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