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Morphometrics of Second Iron Age ceramics – strengths, weaknesses, and comparison with traditional typology

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ABSTRACT

Although the potential of geometric morphometrics for the study of archaeological artefacts is recognised, quantitative evaluations of the concordance between such methods and traditional typology are rare. The present work seeks to fill this gap, using as a case study a corpus of 154 complete ceramic vessels from the Bibracte *oppidum* (France), the capital of the Celtic tribe Aedui from the Second Iron Age. Two outline-based approaches were selected: the Elliptic Fourier Analysis and the Discrete Cosine Transform. They were combined with numerous methods of standardisation/normalisation. Although standardisations may use either perimeter or surface, the resulting morphospaces remain comparable, and, interestingly, are also comparable with the morphospace built from traditional typology. Geometric morphometrics also present the advantage of being easily implemented and automated for large sets of artefacts. The method is reproducible and provides quantitative estimates, such as mean shape, and shape diversity of ceramic assemblages, allowing objective inferences to be statistically tested. The approach can easily be generalised and adopted for other kinds of artefacts, to study the level of production standardisation and the evolution of shape over space and time, and to provide information about material and cultural exchanges.

1. Introduction

Ceramics are the most abundant and well-documented archaeological artefacts from the Second Iron Age. Traditionally, ceramics are used to study a wide range of issues: from establishing chronological sequences and cultural entities, through the definition of social, economic and cultural relationships and organisation, to the understanding of how archaeological complexes were formed. Archaeologists seek to answer these questions through the creation and application of ceramic typologies (e.g. Orton et al., 1992; Shepard, 1985).

Typology aims at assigning ceramic fragments to predefined types. Classification uses one or several discriminant criteria, such as the overall form, the shape of a particular ceramic part (body, rim, foot…), the decoration, or the clay used. Although the method has been proved to be effective for treating huge ceramic assemblages, it may be affected by operator subjectivity, ensuing from specialisation, personal skills and professional experience. This has been demonstrated by the pioneer work of Hodson et al. (1966) on Iron Age brooches. To improve objectivity, at least in data treatment, over the past few decades, archaeologists have introduced statistical techniques, such as the popular seriation (Kendal, 1969, 1971) and cluster analysis (Hodson, 1970), occasionally supplemented by other methods, such as non-metric multidimensional scaling (Drennan, 1976), correspondence analysis (Duff, 1996), principal component analysis (Hodson, 1969) or principal coordinate analysis (Camiz et al., 2003). However, these approaches cannot overcome drawbacks related to the choice of relevant descriptors, and also to difficulties which may arise in coding the state of categorical variables without any ambiguity.

Recent developments in image, video and audio processing have led to remarkable advances in geometric morphometrics, used

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nowadays to study shapes in a broad range of fields. Many studies by anthropologists and evolutionary biologists are now based on these techniques (e.g. Slice, 2005; Zelditch et al., 2004), while their application in archaeology, except for biological remains (physical anthropology, archaeozoology, archaeobotany, and palynology; e.g. Ottoni et al., 2013; Terral et al., 2010; Vigne et al., 2007) is rarer and more recent (e.g. Karasik and Smilansky, 2008, 2011; Saragusti et al., 2005). Nonetheless, their potential for expressing forms unambiguously has been successfully exploited to study lithic artefacts (Brande and Saragusti, 1996; Buchanan, 2006; Buchanan and Collard, 2007, 2010; Lycett, 2009 and citations therein), sculptures (Buxeda i Garrigós and Gordaliza, 2011; Urbanová et al., 2011) and Bronze Age axes (Forel et al., 2009; Monna et al., 2013). Up to now, morphometric applications for ceramic taxonomy are scarce, but very promising: Gilboa et al. (2004) used computational typology to classify ceramics, while other authors have examined the potential of morphometrics for predicting the complete form from shards that include the rim or the bottom of the vessel (Karasik and Smilansky, 2011; Martínez-Carrillo et al., 2009, 2010). In practice, several parameters of geometric morphometrics can be fine-tuned, from sampling resolution and size normalisation (*i.e.* the acquisition process and shape definition), to the computation of shape variables.

The corpus used here was discovered at the *oppidum* of Bibracte, Burgundy, France. During the late Second Iron Age, Bibracte was the capital of a Celtic tribe, the *Aedui*. Archaeological excavations, undertaken each year over several decades, have unearthed a wide variety of ceramics, from plates to bottles (Barral et al., 1995; Paunier and Luginbühl, 2004; Paunier et al., 1994). If properly applied, computer-intensive techniques can do far more than merely categorise objects that can be readily differentiated by the naked eye. The present work provides an assessment of various operational combinations, considering either open contours treated by Discrete Cosine Transform (DCT) or closed contours treated by Elliptic Fourier Analysis (EFA), where the effects of size and orientation have been removed with different normalisation techniques. These approaches correspond to different ways of apprehending the ceramic shape. All these combinations produce morphospaces, which were all compared with each other and with the morphospace produced by more traditional descriptive methods (Vaginay and Guichard, 1988). Thus, it is possible to evaluate *i*) the pertinence of the traditional typology using several different quantitative estimates of shapes, and *ii*) the strengths and weaknesses of these various definitions of ceramic shapes in an operational context.

Morphometrics allows the calculation of an average shape, an idealised centroid shape, which takes into account all the individuals in the group, and not merely a single element, supposed to be the best representation, as often used in typology. Another parameter of interest is the diversity of shape within a group, which is at least as important as the mean shape, and may reveal the level of product standardisation of a given ceramic type. These two parameters are also explored here.

2. Material and methods

2.1. Corpus

Data were acquired from a corpus composed of ceramics discovered at Bibracte, all dating from the 2nd century B.C. to the beginning of the 1st century A.D. Only items presenting a complete, well-preserved cross-section, for which drawings are available in the literature, were retained for the present study (literature details are available in Supplementary materials S1). Although the "complete, well-preserved cross-section" constraint considerably downsizes the number of analysable individuals, drawings of 154 ceramics were processed. Some may not be entirely reliable because of the errors inherent in any manual representation (lack of precision, possible interpretation in the drawing process, etc.). However, the disparity of the corpus is large enough to render such uncertainties negligible.

Using the well-established typological system of Bibracte (Barral et al., 1995), the 154 ceramics studied were attributed to 8 main functions on the basis of their shape: 35 plates, 20 dishes, 24 bowls, 18 cups, 14 goblets, 27 pots, 9 vases and 7 bottles.

2.2. Numerical analysis of classical typology

2.2.1. Character coding

Structured descriptive typology elaborated by Vaginay and Guichard (1988) for a contemporary site (Feurs, Rhône-Alpes, France) has been selected to describe our ceramics. Such a system allows the shape similarity between items to be quantified using a combination of several observed features, categorised metric indexes and angles. Only descriptors directly related to the morphology of vessels were taken into account. For some descriptors, additional levels were added to allow a full description of items from Bibracte (see Supplementary materials S2 for details). The final descriptive system consists of 15 categorical descriptors, each with between 2 and 10 levels.

2.2.2. Similarity computation between ceramics

The degree of resemblance between objects was achieved by computing Gower's coefficient (Gower, 1971; Legendre and Legendre, 1998) from the 15 categorical descriptors mentioned above. This similarity coefficient, $S_{i,j}$, between two individuals (*i* and *j*) for *p* variables, was computed following:

$$S_{i,j} = \frac{\sum_{k=1}^{p} w_{i,j,k} g_{i,j,k}}{\sum_{k=1}^{p} w_{i,j,k}}, \quad (1)$$

where all variables were treated as qualitative. Therefore $g_{i,j,k} = 1$ when both character states agree, and 0 otherwise. Kronecker's delta $w_{i,j,k}$ is a weight equal to 0 when the information is missing, and which evolves between 0 and 1 otherwise, allowing more weight to be ascribed to the most important descriptors for typological distinction. An arbitrary triple weight was attributed to certain descriptors characterising the whole form, because they are fundamental in traditional typology to identify the main types (see Supplementary materials S2 for details). The absence of certain signs for two items, for example the absence of a foot, was considered as an indicator of similarity, so that $g_{i,j,k} = 1$ in such cases. A Principal Coordinate Analysis (PCoA), also called metric multidimensional scaling, was computed to visualise the level of similarity of items. In practice, this analysis used a dissimilarity matrix D. The transformation $D = \sqrt{1 - S}$ was preferred for computation because it is less likely to generate negative eigenvalues, synonymous with non-Euclidean dimensions (Legendre and Legendre, 1998).

2.3. Morphometrics

2.3.1. Sampling outlines

Drawings were scanned in greyscale at a resolution of 1200 dpi and stored in TIF format. All images were oriented on the natural axis on which the artefacts originally stood. After possible noise had been eliminated from the scans, the half cross-section was extracted, in the *R* environment (R Core Team, 2012), using a modified version of the function "`conte`" (Claude, 2008). Sampling was at