Investigating social change during cultural contact period using geometric morphometry of pottery shapes from Iron Age northeastern Taiwan

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The emergence of ceramic specialization in prehistoric societies is often linked to shifts in the complexity of social structures, because specialized pottery production can reflect craft specialization and the presence of elite control. Previous work on identifying specialization relies on typological or linear metric analysis. Here we demonstrate how to investigate ceramic standardization by analyzing outlines of ceramic vessels. Outline analysis is an important method because, unlike more commonly-used landmark analysis methods, it can effectively quantify shape differences for objects that lack distinctive measurement points needed for landmark analysis. We demonstrate this method using pottery from Kiwulan, a large multi-component Iron Age site (AD 1350-1850) in northeast Taiwan. To measure ceramic specialization, we quantified pottery standardization by analyzing shape variables with reproducible geometric morphometric methods. We computed coefficients of variation (CVs) for shape coefficients obtained by elliptical Fourier analysis to test for shape standardization. We found significant differences in pottery shape and shape standardization that indicate changes in pottery production resulting from contact with mainland Han Chinese groups in northeast Taiwan. We infer increasing craft specialization and changes in social organization. Our case study, which includes an openly available research compendium of R code, represents an innovative application of outline-based methods in geometric morphometry to answer the anthropological questions of craft specialization. This study implies that craft specialization can be a deliberate act of resistance to show indigenous identity and ethnicity in a direct culture contact situation.

# Introduction

The development of craft specialization is usually associated with the social changes since it reflects production systems that inform social, economic, or political conditions of a society. Specialization is defined as “differential participation in specific economic activities”, in which a particular good is produced by fewer producers compared to the total population who consume it (Costin, 2001, p. 43, 1991). The implication of the emergence of specialization for social structure or social process has been a theme in archaeological investigations. According to the political approaches, craft specialization, attached production specifically, is viewed as a strategy used by elites to control over production systems for the sake of power and authority (Costin, 2001). The relationship between craft specialization and social differentiation is broadly discussed, and many cases show that specialized production can be a useful indicator of increasing socio-political complexity (Hirshman et al., 2010; Junker, 1999). Economic models consider production, exchange, and consumption as a whole to explain specialization as a subsistence strategy to accommodate uneven distribute of resources (Arnold and Munns, 1994; Costin, 2001), a reaction to the changes in subsistence practices (Stark, 1995a), or an outcome stimulated by long-distance trade and inter-regional exchange (Alizadeh et al., 2018). An present-day investigation of ceramic specialization in the Jodhpur region of India suggests that the adoption of standardized products across cultural boundaries is a reaction to a collapse of previous economic system, indicating the correlation with major socio-economic changes (Roux, 2015). However, it is important to note that the explanation for the emergence of specialized production might not be exclusive or straightforward. Moreover, Acabado et al. (2018)’s case study in lowland northern Philippines shows that specialization is not necessarily accompanied with social differentiation based on the result of a low degree of ceramic specialization in Ifugao ranked societies during the Spanish colonization. The development of specialization could be history dependent, where condition and contexts under which specialists organized are important for interpretation of changes in social organization (Costin, 2001; Roux, 2015).

The emergence of social inequality in the context of cross-cultural interaction especially in a colonial situation was observed in many parts of world when the introduction of foreign trade goods to local indigenous societies. The monopolization of long-distance trade goods usaully cause substantial transformations of indigenous economic, cultural, and socio-political systems (Dietler, 2005, 1997; Junker, 1993; Silliman, 2005). Recently more studies discuss the indirect effects of colonialism or pericolonial archaeology that investigates areas where European colonial rule was limited or their conquests were unsuccessful, but their colonial activities had economically and politically impacts on indigenous peoples in the periphery of colonial control (Acabado, 2017; Trabert, 2017). For example, Acabado (2017)’s study on Ifugao society in the highland Philippines suggests economic and political intensification during the Spanish presence as the response of indigenous peoples to the Spanish cooptation. Indigenous societies might not just passively accept the colonial rules, but instead actively negotiated with the colonist, and accommodate or resist the foreign intrusion through their daily cultural practices, such as consumption patterns of foreign goods (Dietler, 2015; Given, 2004; Mullins, 2011; Scaramelli and Scaramelli, 2005; Silliman, 2001; Torrence and Clarke, 2000). The archaeological evidence in northeastern Taiwan show evidence of increasing use of prestige goods such as trade ornaments and uneven distribution pattern in domestic area and burial contexts when the society encountered by the Spanish and the Dutch in the 17th century. In addition to the differential distribution of trade ornaments, the locally made ceramic present a high consistency in form and shape compared to other pottery throughout northeastern Taiwan that hints the possibility of pottery specialization.

To identify craft specialization, the variation of standardization of specialized product is commonly used as indicator based on the assumption that specialized mass production will lead to uniformity of the product due to routinization, increased skills, and fewer number of producers involved in production (Costin, 2001, 1991; Stark, 1995b). For ceramic standardization, several measurements have been proposed and discussed, such as metric, compositional, and technological approaches (Arnold, 2000; Blackman et al., 1993; Boness et al., 2015; Costin, 1991; Rice, 1991; Roux, 2015; Tite, 1999). Among those variables, metric measurement is widely applied in archaeological assemblages by calculating coefficient of variation for sets of data coupled with statistical comparison to identify lower value as an indicator of higher degree of standardization (Eerkens and Bettinger, 2001; Roux, 2003; Stark, 1995b). Roux and Karasik (2018)’s ethnographic study in the Jodhpur region of India suggests the number of artisans can be assessed by comparing coefficient of variation and the differences between artisans can be detected at both intra-individual level and inter-individual level in a region. Although this traditional typological and linear measurements are useful for identifying differences in archaeological assembles, it might be limited because dimensional measurements can be insensitive to subtle variations resulting from changes in assemblages. Shape analysis based on geometric morphometrics method are new approaches for measuring the degree of standardization since it takes the overall shape as variable for comparison (Slice, 2007). Using geometric morphometrics approaches, we study shape and standardization of locally made ceramics at Kiwulan (1350-1950 AD) (Chen, 2007), a large multi-component archaeological site in northeastern Taiwan, to identify changes in ceramic production in cross-cultural interaction contexts. The aim of this paper is to investigate if there are increasing ceramic specialization resulting from interaction with the Europeans in the 17th century or the Chinese in the 19th century, two major foreign influences in early historical Taiwan, that might indicate social changes in the indigenous society.

Our hypothesis is that if foreign influences had impacts on the emergence of social inequality in local indigenous society due to the monopolies for trade between a small number of indigenous people, then we expect to see the changes in social organization from a more corporate to a more network organization that would be reflected by pottery production at Kiwulan (Feinman, 2000). The emergence of craft specialization, here pottery specialization, are usually related to changes in social organization towards a society with increasing status inequality. In this case, if the competitions for foreign resources and being trade partners of European or Chinese colonizer among individuals gradually lead to increasing social inequality, then we expect the local ceramic will show more homogeneous features after contact due to the craft specialization caused by control of small group of individuals. This study is important to understand the indirect influences of the European colonists on the local indigenous societies, which remains unclear in East Asia where the colonial power was not successful compared to other places in Southeast Asia. Also, it would help to understand the relationship among the use of prestige goods, the degree of ceramic specialization, and the influence of foreign colonizers in a pericolonial context (Acabado, 2017).

## Geometric Morphometric approaches

Geometric morphometric methods (GMM) has been increasingly applied in archaeology for shape analysis, which explores morphological variability and similarity of archaeological materials to address the questions of anthropological interests. Different from linear measurement approaches that capture shapes by measuring length, width or ratios of objects, geometric morphometrics methods use Cartesian coordinates of morphological structures to define shapes (Adams et al., 2004; Bookstein, 1997; Lawing and Polly, 2010; Slice, 2007). Landmarks, curves or outlines of objects can be represented by coordinates in terms of their unique point locations with respect to numerical values of coordinate axes. According to different focuses and nature of original shape data, there are two common morphometric methods, landmark approaches and outline approaches (Adams et al., 2004). Landmark approaches assign a set of landmarks or semilandmarks onto objects as reference points that can be specified on a coordinate system as x, y coordinates for two dimensions, or x, y, z coordinates for three dimensions. Based on distances between raw landmarks, objects are translated to a common centroid, rescaled into the same size, and rotated until the summed squared distances between corresponding landmarks are minimized using generalized Procrustes analysis (GPA) (Bookstein, 1991). GPA is a method that superimposes sets of landmark configurations into a common coordinate system, where superimposed landmark coordinates are used as shape variables for further multivariate statistics analyses (Slice, 2007). Landmark-based morphometrics are widely applied to archaeological objects with a obvious morphological signature that can provide ideal reference points for landmark placement, such as projectile point tips or biologically measurements points indicating osteological features (Birch and Martinón-Torres, 2019; Buchanan et al., 2019; Cardillo, 2010; Haruda et al., 2019; Lycett and Cramon-Taubadel, 2013; Meloro et al., 2015).

However, one limitation of landmark approaches is that landmark data may not be able to capture the shape differences of a morphological structure where the curving outlines between landmarks are crucial for variation. Furthermore, representative and reliable landmark points may be unavailable for complex or rounded shaped structures. In those cases, outline approaches are better way for analyzing the overall shape of an object. One of the outline approaches is the semi-landmarks method, also called sliding landmarks, which assigns points along the curve between two landmarks at defined intervals (Bookstein, 1997; Lawing and Polly, 2010). Those semi-landmarks are allowed to slide along the curve to remove the effect of the arbitrary landmark spacing by minimizing either Procrustes distance or bending energy (Bookstein, 1997; Gunz and Mitteroecker, 2013; Slice, 2007). Another approach is elliptic Fourier Analysis (EFA) that turns coordinates into coefficients using mathematical function, commonly applied to two-dimensional closed shape (Kuhl and Giardina, 1982). EFA uses periodic functions to capture geometric information, where an outline is decomposed into a series of ellipses described by trigonometric functions, called harmonic coefficients (Adams et al., 2004; Bonhomme et al., 2014; Claude, 2008). The number of harmonics determines the quality and precision of the geometry of an object. The harmonic power, a cumulated sum of squared harmonic coefficient, provides a robust rule for the desired number of harmonics (Bonhomme et al., 2014).

Outline approaches especially EFA is suitable for shapes lacking representative landmarks or curves convey more meaningful variations. The applications in archaeology are seen on human remains or zooarchaeology to understand the biological variation and recently more on stone artifacts to explore stone tool technology (Fox, 2015; Hoggard et al., 2019; Ioviţă, 2010). Ceramics is another archaeological materials that outline approaches can provide new insights into shape variation to answer anthropological questions related to ceramic specialization. Using semi-landmarks method, Topi et al. (2018) examine 89 photographs of globular jars from the Casas Grandes of northwest Mexico. Their results suggest that some ceramic types from Medio period (AD 1200-1450), were made by specialists based on high standardized shape. Among those high standardized jars, some were made by attached specialists, while others were made by independent specialists according to their spatial distribution patterns. Similarity, Selden Jr (2019) examines 28 Caddo bottle excavated at several sites (AD 500-1700) in northwest Louisiana from the Clarence H. Webb collections. The results indicate a significant integration between the different parts of the bottles including rim, neck, body, and base that vary in a coordinated manner. Also, two discrete base and body shapes represented north and south difference were identified. For the EFA method, Wilczek et al. (2014) evaluate the concordance between EFA and Discrete Cosine Transform (DCT), and traditional typology by studying 154 complete ceramic vessels with varied shapes from the Bibracte oppidum in France. The results show the variation indicated by EFA and DCT matches traditional ceramic typology, which supports that outline-based approaches can be efficiently used for studying variations in ceramic shapes. Furthermore, the EFA results help to understand the level of production standardization over time across the region. Those examples show that outline approaches can distinguish variation in ceramic shapes in a finer resolution to understand deeply the ceramic production.

Taking the ceramics data from Kiwulan, northeaster Taiwan, we use EFA to evaluate the level of standardization of ceramics in relation to the European presence in the 17th century that might hint the emergence of ceramic specialization. In addition, we use significance test for the equality of coefficient of variation of shape variables to compare the vessel standarization from different periods in a statistical way. Using pottery shape as a proxy to study craft specialization, we answer the questions: Did foreign influence have impacts on indigenous pottery production that can be detected in the shape of the vessels? How does pottery change in shape in relation to foreign influences? Did pottery become more homogeneous and standardized in shape after foreign contacts with the European colonizer or the Chinese immigrants? Starting from the historical background of colonial influences and its reflection in the material record, this study explore the relationship between the emergence of social inequality and craft specialization that can extend our understanding of the reactions of indigenous societies in the periphery of colonial control, providing a perspective that could be applied in other parts of the world in a similar context.

# Materials and archaeological background

Ceramics analyzed in this paper come from 40 units (4m by 4m) sampled from the largest excavation section at Kiwulan, northeastern Taiwan (Figure 1; Figure 2). Kiwulan is situated on a hill near a riverside at the northern margin of Yilan, which is characterized by a triangular alluvial plain facing eastwards the Pacific with high mountains on three other sides . Yilan is an ideal context to study peripheral colonial influence because it was relatively isolated by natural barrier that reduced frequency of direct contact with the Europeans presences, the Spanish and the Dutch settled in northern Taiwan. The chronology of Kiwulan consists of two cultural components, the upper component and the lower component, with a sterile layer in between (Chen, 2007). This paper focuses on the upper component dated from AD 1350 to AD 1950, covering the late Iron Age and the historical period defined by the European presence in Taiwan in the early 17th century. The Dutch firstly came and occupied southern Taiwan in 1624 and then the Spanish occupied northern Taiwan in 1626. In 1642, the Spanish was expelled by the Dutch, who took over their forts in northern Taiwan. Since then, western Taiwan was mostly under the colonial rule of the Dutch until 1662 when the Kingdom of Tungning in Taiwan was founded by Koxinga, a loyalist of the Ming dynasty of China (Andrade, 2007).

The upper component experienced foreign contacts including the Europeans in the 17th century and great waves of Chinese immigrants in the 19th century. Imported ceramics from mainland China, stonewares, and ornaments elements such as beads were trade goods commonly found in the upper component that indicates the frequent long-distance trade activities in the 17th century during the European presence in northern Taiwan. In addition to artifacts, features such as burials, middens, and post-holes with in-situ posts widespread across 1-2 m thick deposit explain that Kiwulan was a continuously occupied and large settlement site (Chen, 2007). To compare different foreign influences, the upper component were classified into three phases, the pre-European, European, and Chinese periods. The principle of identification of three phases is based on 32 radiocarbon ages, excavation depth, consistency of contexts, and types of chronologically diagnostic artifacts, such as blue and white porcelains, light grey glazed jars, and large dark brown glazed stoneware jars prevailing in the 17th century, and bricks and tiles used by the Chinese in the 19th century (Hsieh, 2009; Wang, 2011). The deposit shows signs of continuous human occupation during each of the three phases across the sampling area.

The predominant artefact found is locally made ceramics, which distributed throughout the sequence across the site. More than 550 thousands of sherds were excavated, and around 1,200 vessels were reconstructed. It is interesting to note that there are only two forms of local vessels, one is cooking pot and another one is steamer made of two cooking pots stacked together with a filter clay layer in between. Those pots show high consistency in shape. They are globular body with short neck and wide mouth. The exterior surface below the neck is treated with a wide variety of impressed geometric motifs. They were believed used for cooking based on the evidence of charred residues and carbon deposits commonly observed on the interior and soot on the exterior. Moreover, a lack of evidence of other utilitarian earthenware ceramics suggests this globular pot was mainly used for daily cooking. They are fired to orange to brownish color with a fully oxidized core or a reduced core with oxidized fringes. Finger impressions and seams usually on the interior indicate they were pinched using slabs of clay and shaped by hand. In addition to Kiwulan site, this kind of pot was widely found at other archaeological sites during the same period in Yilan Plain.



Figure 1: Map showing the location of Kiwulan, and other places in northern Taiwan named in the text. Map data from naturalearthdata.com



Figure 2: Map showing the largest section of excavation areas at Kiwulan, and the distribution of forty squares sampled in this paper presented in red with square ID number. Small dots represent the location of post-holes. Each square is 4 x 4 m

Petrographic analysis for 34 thin sections shows high percentage of inclusions (15-50%), including argillite, quartz, feldspar, metasandstone, sandstone fragment, and slate. The most common type of sherds, also the dominant one, has a high percentage of inclusion (25-40%), which is composed mainly by argillite (15-40%), followed by metasandstone (1-10%), sandstone (1-6%), and quartz (1-5%). The size of the particles ranges from 500 micron to 1300 micron (=1 mm). In general, this type presents a mixture of fine, rounded argillite with a small part of rounded metasandstone and rounded to sub-angular monocrystalline quartz. The composition matches the mineralogical composition of local raw materials in the Yilan Plain (Chen, 2016). It seems there is no obvious changes in the inclusions over time.

# Methods

A total of 73 vessels from pre-contact contexts (n = 32), post-European contexts (n = 27), and Chinese contact contexts (n = 14) were selected for Ellipic Fourier analysis due to their completeness covering most parts from rim to bottom. To fully explore the pottery standardization, we also take the metric measurements into account as a basis for comparison. The total of 362 reconstructed pots (pre-European = 153, European = 173, Chinese = 36) were measured. The metric attributes include thickness of rim, neck, and body, and diameter of rim, neck, and body. For each pot, two measurements for thickness and diameter were took to compute an average value. To obtain information about the pottery shape, we also compare the ratio of Rim/Body thickness, and the ratio of Rim/Body diameter.

## Digitising and analysing by EFA

The scanned pottery drawings of those pots were acquired from Bureau of Cultural Affairs in Yilan. All drawing presents two-dimensional view of the section of a vessel with indications of metric measurements. The scanned drawings were imported into the Inkscape software for outlines tracing to remove additional information such as marks, lines, and measurements on the original drawings. Each traced half cross-section image was duplicated, flipped, and then joined with another one to create a 2D closed outline. Geometric morphometric analyses were conducted in the R software (www.rproject.org, Core-Team, 2015) using the functions included in the Momocs, a R package intended to quantify the shape and compare its variation, especially for outline analysis (Bonhomme et al., 2014). The digitised outlines were converted into a list of successive x-y pixel coordinates for elliptic Fourier analysis (EFA), which assesses morphological differences among pottery shapes from three occupation contexts. The harmonic coefficients generated by EFA were analysed by principal component analysis (PCA) to illustrate the diversity of the shape data and identify the major patterns of variation through dimensionality reduction.

## Statistical testing

The principal components (PCs) scores were analysed with a multivariate analysis of variance (MANOVA) to test for significant effects of the groups of occupation context on shape variances. Finally, we computed coefficients of variation statistic (CVs) among multiple groups of PCs with a significance test for the equality of CVs, which enable us to compare CVs in a statistical way (Karl Pearson 1896). The coefficient of variation is a common and widely-used statistical measure of the spread of a set of measurements of a sample. It is defined as the standard deviation divided by the mean in a ratio scale format.

By standardizing standard deviation in each data set, the coefficients of variation statistics allows us to directly compare variation in samples measured with different units or means. Although it is a useful method, there is a question that how should we make a decision that the differences among the multiple CVs are significant or not? To answer this question, we need convenient methods for testing the equality of values from different samples, which has been described in many publications and here we proposed a significant test for CVs using the R package cvequality (Marwick and Krishnamoorthy, n.d.) in the CRAN repository. The package cvequality includes two tests, the “Asymptotic test for the equality of coefficients of variation from k populations” (Feltz and Miller 1996) and the “Modified signed-likelihood ratio test (SLRT) for equality of CVs” (Krishnamoorthy and Lee 2014). Feltz and Miller (1996) test is widely cited as an authoritative test for the equality of values that performs better than many approximative tests. It is a ‘gold standard’ test for comparing multiple . Our implementation is based on the following from Feltz and Miller (1996):

Let be the observed standard deviation of the th sample (or group of measurements), be the observed mean of the th sample, and let

and we do not know the population , so let be an estimate as follows:

where

Then the test statistic can be computed with:

The value measures how far each sample is from our estimate of the population . Feltz and Miller (1996) note that the value distributes as a central random variable with degrees of freedom, from which a p-value can be computed. We also include the Krishnamoorthy and Lee (2014) test as a more recent development with lower rates of type I error, better performance with uneven sample numbers, and more power across a range of conditions.

# Reproducibility and open source materials

To enable re-use of materials and improve reproducibility and transparency (Marwick, 2017), the entire R code (R Core Team, 2019) used for all the analysis and visualizations contained in this paper is included in <http:XXX>. Also in this version-controlled compendium (Marwick et al., 2018) are the raw data for all the visualizations and tests reported here. All of the figures, tables, and statistical test results presented here can be independently reproduced with the code and data in this repository. The code is released under the MIT license, the data as CC-0, and figures as CC-BY, to enable maximum re-use.

# Results

Table 1: Coefficient of Variation test for metric attributes by phases

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| variable | pre-European | after European | Chinese | MSLRT | p\_value |
| Rim thickness (mm) | 23.0893 | 26.3245 | 21.816563 | 3.3113 | 0.1910 |
| Neck thickness (mm) | 17.3862 | 20.3716 | 19.860990 | 3.6368 | 0.1623 |
| Body thickness (mm) | 25.9332 | 28.6251 | 24.188732 | 2.2762 | 0.3204 |
| Ratio of Rim/Body thickness | 31.9633 | 30.7785 | 30.060009 | 0.3057 | 0.8583 |
| Rim diameter (mm) | 6.8355 | 9.6082 | 6.929983 | 19.2422 | 0.0001 |
| Neck diameter (mm) | 10.6207 | 7.7212 | 7.065821 | 19.0681 | 0.0001 |
| Body diameter (mm) | 9.2486 | 8.8551 | 6.561998 | 4.9965 | 0.0822 |
| Ratio of Rim/Body diameter | 6.6892 | 7.2115 | 7.029331 | 0.7344 | 0.6927 |

Table 1 shows the results of Modified signed-likelihood ratio test (MSLRT) for equality of CVs for for six measurements and two ratio values. There is a significant difference (p-value less than 0.01) between CV values for two metric measurements across phases, the rim diameter and the neck diameter. The CV values show that the variation of rim diameter is small (6.8%) before European contact, increases after the European presence (9.6%), and decreases after the Chinese presence (6.9%). For the neck diameter, the CV values indicate smaller variation after the European period (7.7%) and the Chinese period (7.1%) compared to pre-European period (10.6%).

The elliptic Fourier coefficients of 73 pottery from three phases were calculated. Reliable pottery outline was captured by 13 harmonics that gather 99 % of the total harmonic power. The average shape of vessels from each phase was visualized by computing the mean of the standardized Fourier coefficients within each phase group (Figure 3). Figure 4 shows the shape changes described using thin-plate spline warping for paired periods, pre and post European periods, and post-European and Chinese period in a time sequence.

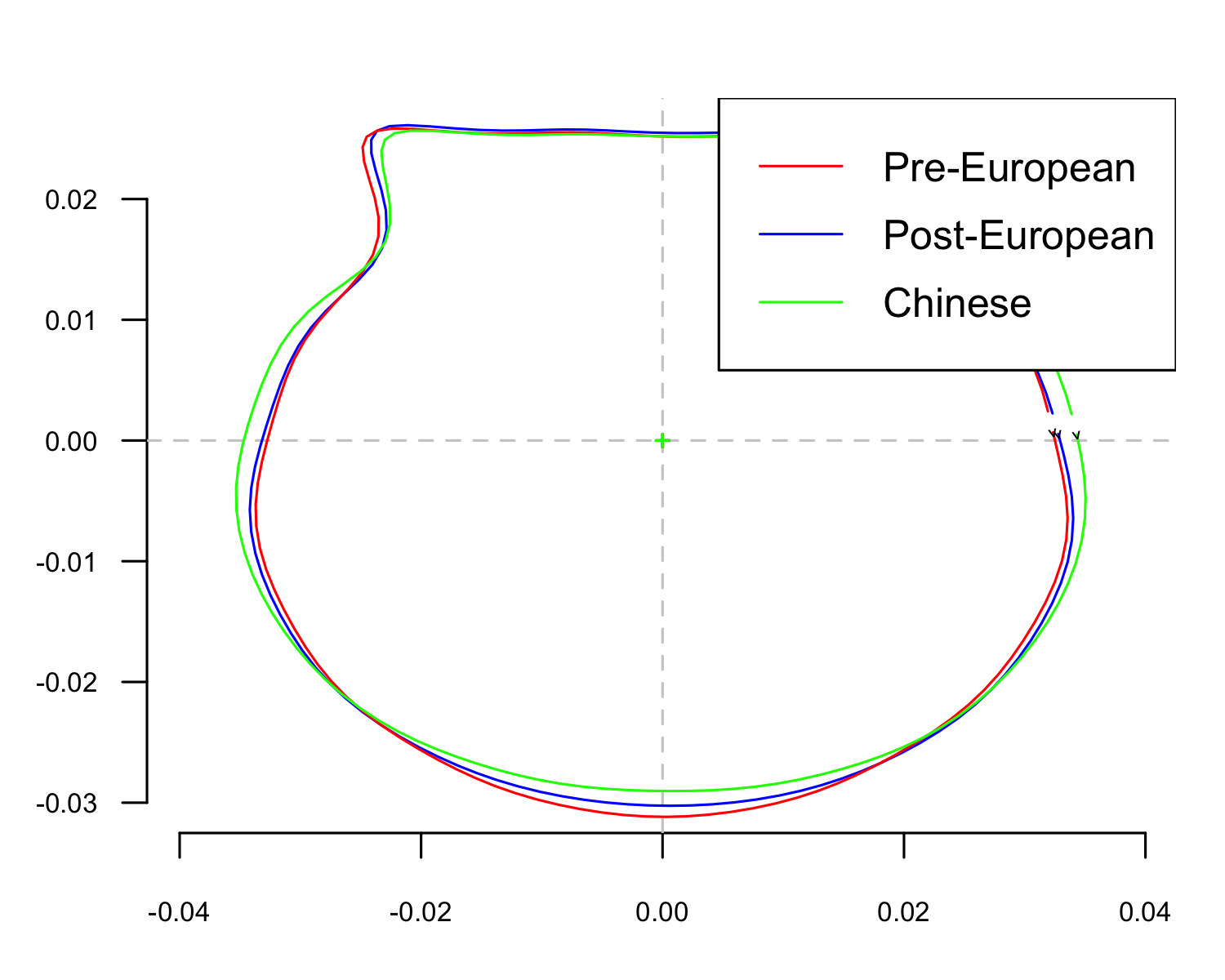


Figure 3: Mean pottery shapes of three phases

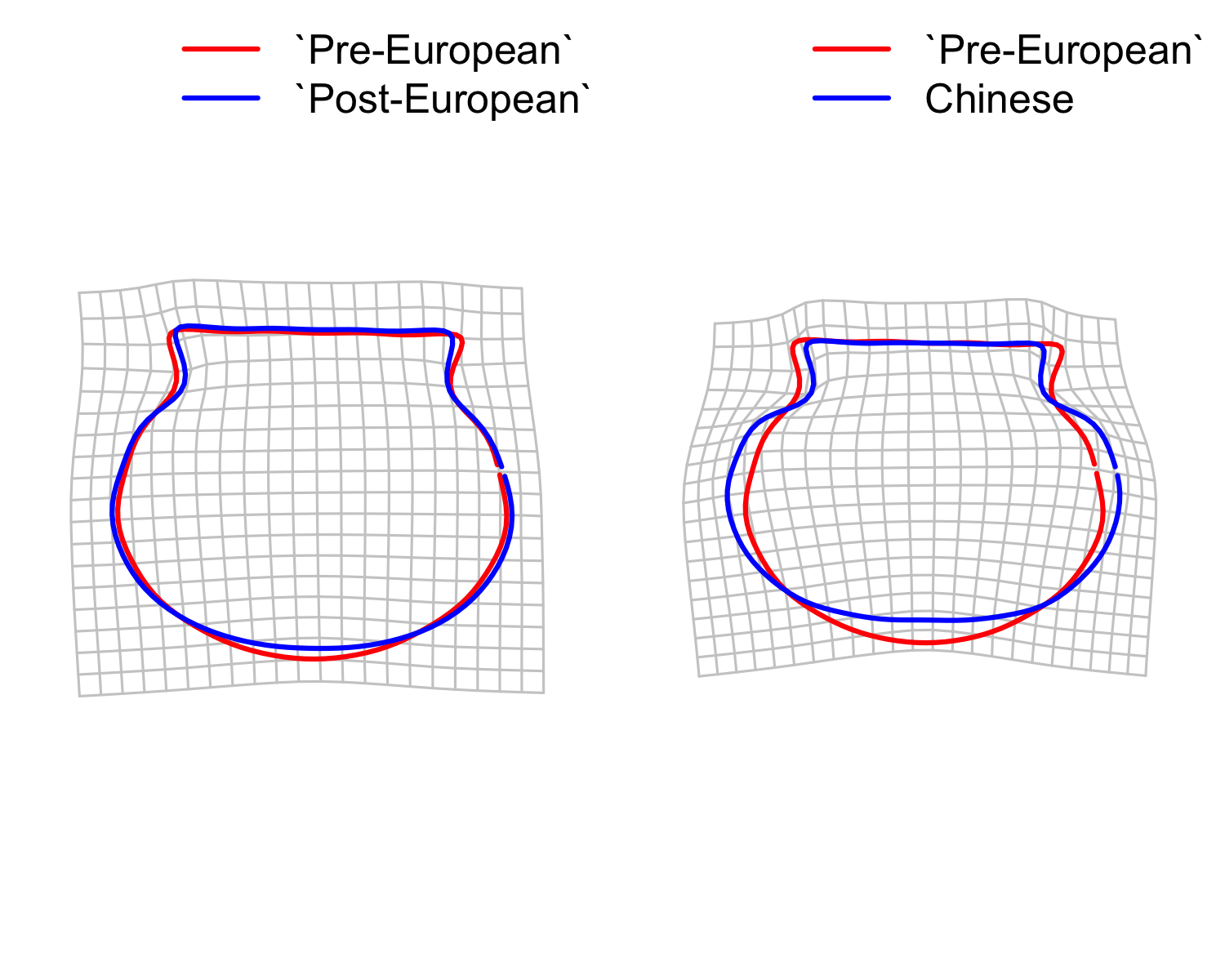


Figure 4: Compare the average shapes across phases using thin plate splines (TPS) with outline deformations required to pass from an extreme of the morphospace to the other.

The elliptic Fourier coefficients are examined by principal components analysis to explore the shape variations across three phases. The first two principal components (PCs) explain 74.85% of the total variances, of which 48.32% is explained by the first principle component. With the third component, the first three principal components explain 86.08% of the total variances. Figure 5 shows the shape variation associated with the first three principal components. From the negative to the positive scores, the PC1 represents the height of the vessels from tall to short and the roundness of the body from round to oval-shaped. The PC2 relates to the neck and mouth constriction from narrow to wide. The PC3 explains a smaller portion of the variance (11.23%), which relates to the degree of the flare of the neck from curved to straight shape. The first two components account for most of the variance in relation to three phases were represented in Figure 6. The result reflects a large overlap of three groupings especially for shapes in the pre-European and post-European periods that might show some extent of the similarity. However, the spread of shape distribution indications a wider variation in shapes in the pre-European and post-European periods compared to those in the Chinese period along both PC1 and PC2 axes. In other words, there is a decreasing in shape variance in the Chinese period that shares the features of shorter height and narrower mouth.

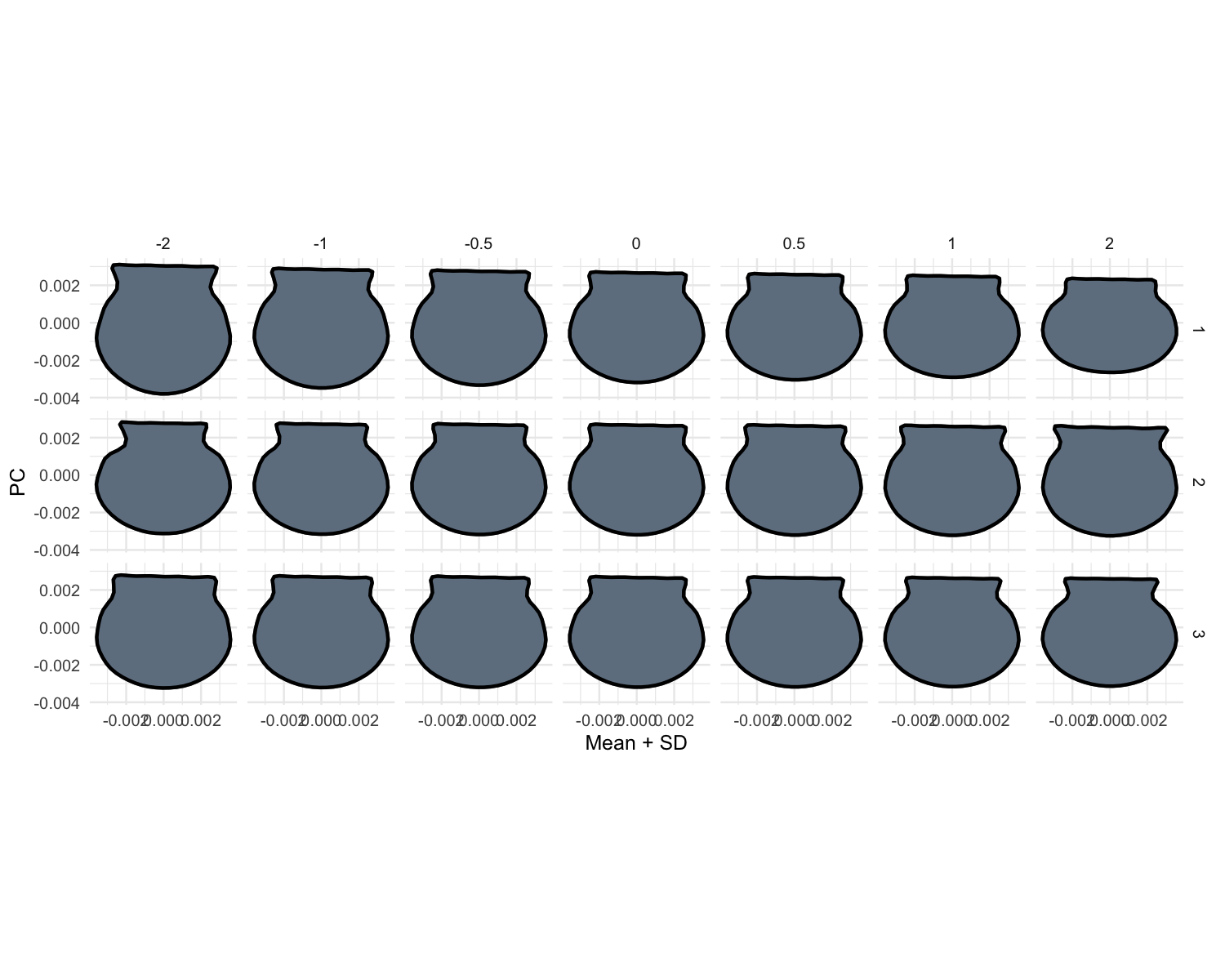


Figure 5: Pottery shape variation based on scores along principal component axes. The rows from the top to the bottom represent the first to third principal component respectively. Each column shows the reconstructed shape variable according to the score mean ±2 standard deviation (SD) with a 0.5 interval

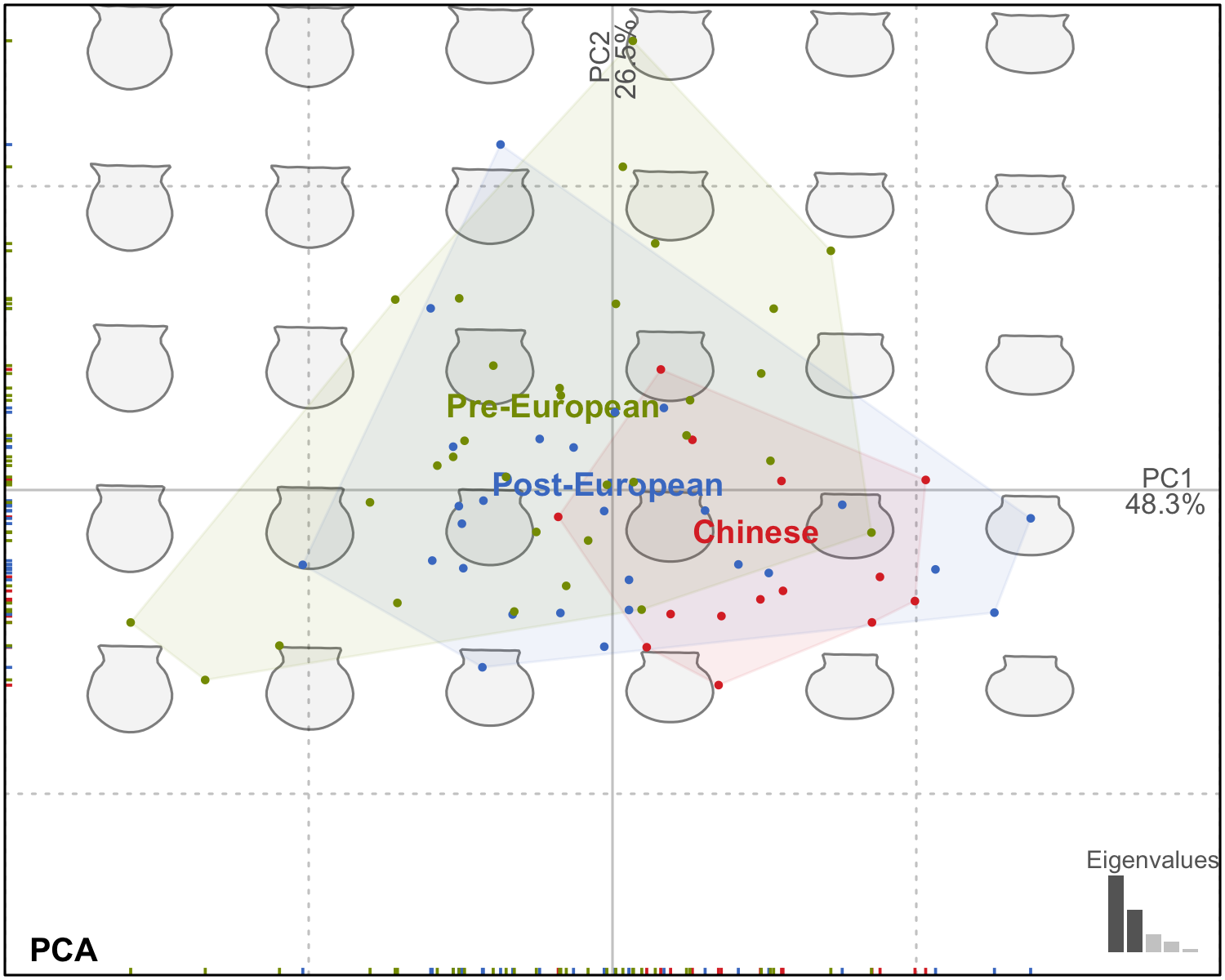


Figure 6: Pottery shape distribution by each occupation phase according to the first two PCs

Table 2: The statistics summary of MANOVA test for the PC scores

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Df | Pillai | approx F | num Df | den Df | Pr(>F) |
| 1 | 0.3806 | 1.6202 | 11 | 29 | 0.1452 |
| 1 | 0.6942 | 7.0177 | 11 | 34 | 0.0000 |
| 1 | 0.3491 | 2.2917 | 11 | 47 | 0.0243 |

To test differences in the distribution of shape variables indicated by the PC scores, we use multivariate analysis of variance (MANOVA) to compare a pairwise combination between every sample means across three phases. The results in Table 2 show significant differences in shape between Pre-European and Post-European (p = ) and Pre-European and Chinese contact shapes (p = ), which corresponds to the previous observation of the different distribution in shapes in Chinese period according to PCA byplot. In addition, although there is a considerable overlap of shape variables between Pre-European and Post-European, their PC scores are significantly different from each other. There are not much differences between the shapes in the Post-European and Chinese contact periods.

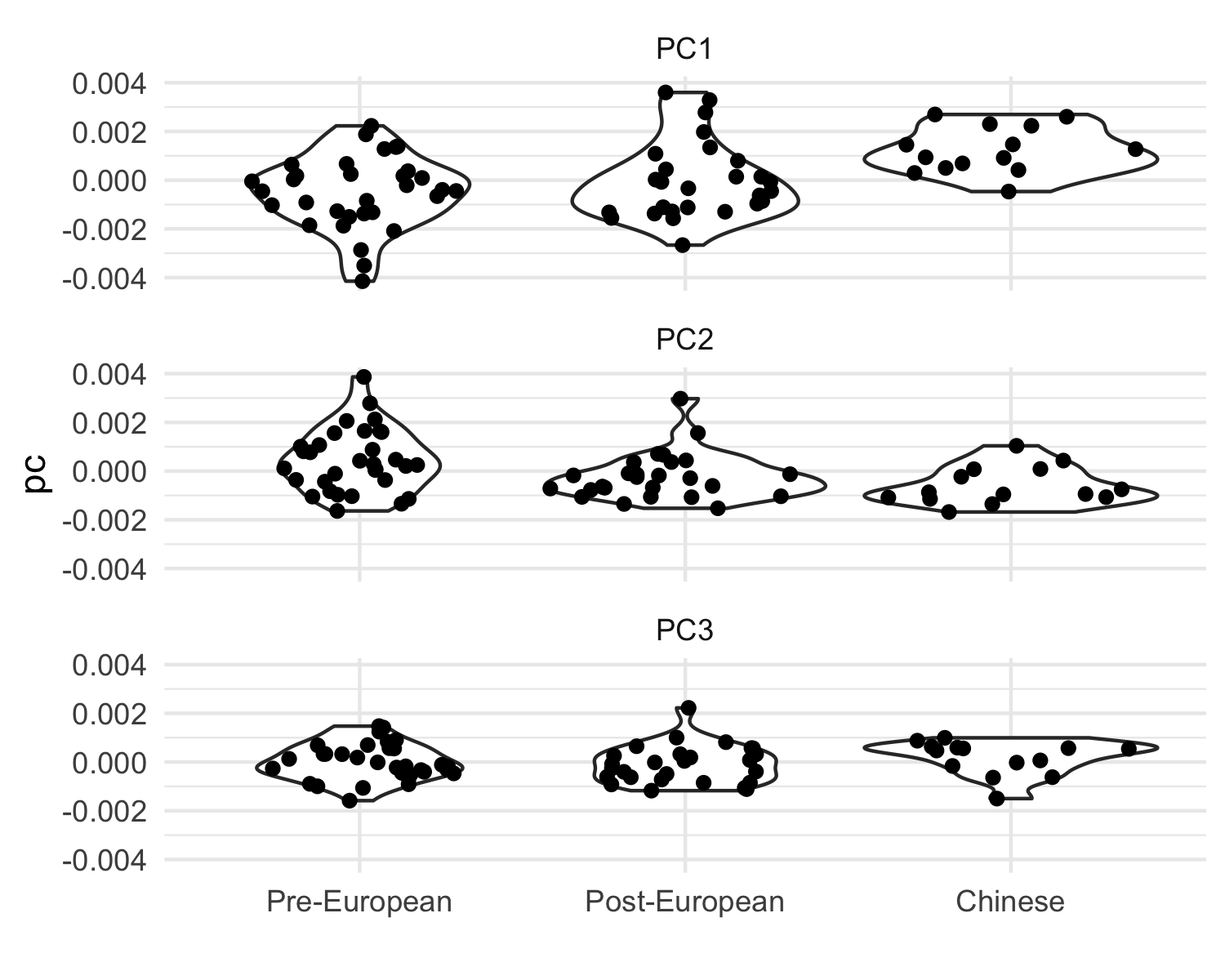


Figure 7: The distribution of PC scores by phases

Table 3: P-values of the CV equality test of PC1 and PC2 between phases

|  |  |  |  |
| --- | --- | --- | --- |
| PC | MSLRT | p\_value | phases |
| PC1 | 2.3213 | 0.1276 | Post-European vs Pre-European |
| PC1 | 13.9989 | 0.0002 | Chinese Contact vs Pre-European |
| PC1 | 8.0358 | 0.0046 | Chinese Contact vs Post-European |
| PC2 | 4.3306 | 0.0374 | Post-European vs Pre-European |
| PC2 | 8.6637 | 0.0032 | Chinese Contact vs Pre-European |
| PC2 | 7.5429 | 0.0060 | Chinese Contact vs Post-European |

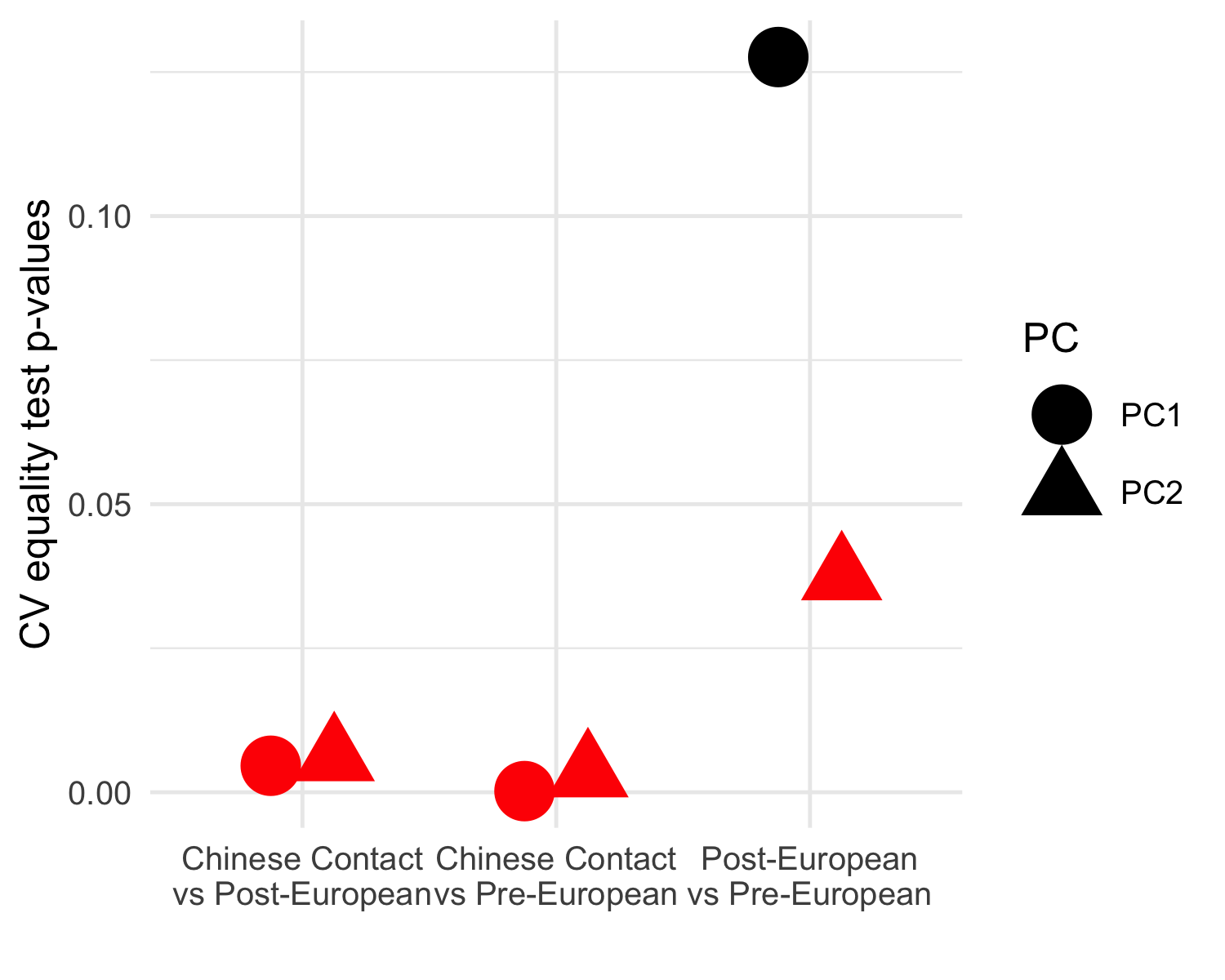


Figure 8: P-values of the CV equality test of PC1 and PC2 between phases, red color indicates p-value is less than 0.05

The variation of pottery shape for each phase is explored by the distributions of the first three PC scores to compare the extent of standardization across phases. Figure 7 suggests variations of PC scores for each vessel by phase. The first PC, the hight of the vessels, shows more variations in the pre-European period compared to the Chinese period. That indicates standardization appears strong in the Chinese period but weak in the pre-European period. The second PC also presents a similar pattern that stronger standardization of shape in the Chinese period compared to the other two phases. To see whether the differences in the distribution of PCs between any two phases is statistically significant, coefficients of variation statistic (CVs) among phase groups of PCs is examined with a modified signed-likelihood ratio test for the equality of CVs. P-values for the significant test of CVs of PC1 and PC2 show significant differences (P-value less than 0.01) in the standardization of vessel shape across some periods, especially between Chinese contact with either pre-European or post-European(Figure 8, Table 3). Significant difference is also detected between pre-European and post-European (P-value less than 0.05). Given the decline of the indigenous population in the Chinese period might be a cause of a more standardized shape (Chen, 2007), we examined the spatial distribution of pottery selected in this paper. The pottery distributed across the sampling area without any clusters could rule out the bias caused by the population dynamics.

# Discussion

Previous investigations at Kiwulan suggest an unequal distribution pattern of prestige goods, trade ornaments specifically, after the presence of the European that hints the emergence of social inequality. We examine the degree of the ceramic standardization to measure ceramic specialization that is usually associate with social differentiation, such as the elite control (Costin, 2001; Junker, 1999). The results confirm that the differences in pottery shapes can be detected using EFA method, indicating the foreign influences on the indigenous society- the Europeans in the 17th century and the Chinese in the 19th century. The result of MANOVA shows there is significant difference in shapes between pre-European and Post-European period, and between the pre-European and the Chinese period. The average shape presents round body with wider rim and neck before the European contact, and turns to oval-shaped body with narrower rim and neck after the European presence and even more obvious during the Chinese contact period. In general, pottery shapes become shorter in hight over time that leads to oval-shaped body. For the standardization of pottery shape, the result of CV test indicates the significant differences between pre-European period and post-European period (P-value less than 0.05), and between Chinese contact and either pre-European or post-European (P-value less than 0.01). This suggests pottery shape becomes more homogeneous and standardized after foreign contacts with the European colonizer and even more with the Chinese immigrants. The compositional analysis shows clay pastes are similar, regardless of the increasing standardization of the pottery shape, reflecting the raw material sources remains unchanged. More standardized shape in the Chinese period might indicate the appearance of specialized group. To figure out whether this change is related to the function of pot, we made an attempt to conduct lipid analysis for potsherds samples to identify the source of residue absorbed into the fabric. However, we did not obtain useful results due to a low lipid yield, which might result from the thin and less porous fabric that offers limited spaces to protect organic molecules from microbiological degradation (Evershed, 2008, p. 909).

The results support part of our hypothesis that foreign influences had impacts on the emergence of social inequality in local indigenous society reflected by the degree of pottery standardization, however, stronger in the Chinese period instead of the European period originally thought to be. The hypothesis of emergence of social inequality based on the monopolies for long-distance trade brought by the Europeans was not fully supported. The nature and context of the interaction with the foreign presences might give an insight into the different degree of standardized pottery. Compared to other region in Taiwan, the European colonial control was weak in Yilan due to the relatively isolated location by mountains and the economic consideration of the Spanish and the Dutch who prefer northern Taiwan as trading base. Yilan could be seen as a place experienced indirect influences by the European trade network and their colonial activities in a pericolonial context (cf. Acabado, 2017). On the contrary, the interaction between indigenous people and the Chinese in the 19th century was more intense and direct since those Chinese immigrants settled in Yilan and lived closely with indigenous societies. This direct influence is reflected by the archaeological evidence of large amount of Chinese porcelains and distinctive architectural bricks and tiles used by Chinese (Hsieh, 2009). Also, the finding of adoption of coffin in mortuary practice that viewed as an ethnic symbol for Chinese was observed (Chen, 2007).

More standardized pottery shape without controlling the clay paste or technology suggests the shape as a preferred characteristic in pottery production during the Chinese period. However, the standardization is not reflected by most metric attributes. There is higher variation in thickness attributes compared to diameter attributes, indicating shape is the main attribute that presents homogeneity. In addition to the emergence of specialized groups indicative of changes in social organization, a further explanation could be that producing homogeneous pottery is an act of resistance to the Europeans intrusion and the the Chinese immigrants by emphasizing the practice of traditional pottery production. In a culture contact situation, social identity could be expressed through materials practices to show cultural homogeneous and distinction from other groups (Voss, 2005). It is also important to recognize that social identity might be more complicated in a colonial context, not just a colonized–colonizer or local/foreign dichotomy (Voss, 2008, 2005). The case study of Shamaoshan cemetery (3BC- 4AD) in Southwest China showing the process of incorporation of Southwest China into Han Empire involved a century of conflicts, resistance, and acceptance among social groups with different identity, especially in the historical context of Han immigrants (Wu et al., 2019). At Kiwulan, the standardization of potter shape is significant in the 19th century when a a large number of Chinese immigrants migrated to Yilan. Shape can be viewed as a symbol as an expression the indigenous identity or social boundary because shape is the most obvious and visible trait compared with other features of pottery (cf. Roux, 2015). Although there is an increase in number of imported ceramics over time and reached high quantity and diversity in the 19th century, the production of the local pottery continued and became more standardized. This might imply not only the utilitarian function, but an deliberate action to emphasize the pottery tradition as their cultural custom.

# Conclusion

This case study demonstrates the application of Elliptic Fourier analysis on ceramic shape to explore the emergence of ceramic specialization and the underlying mechanism indicative of foreign culture influences. Compared with the traditional linear measurement approach, geometric morphometrics methods especially EFA-based outline approach is more effective to detect shape variations for artifact shape without obvious landmarks. Here, EFA approach combined with a significance test for the equality of CVs for shape variables provides a robust way to identify and statistically assess the difference in shape standardization. Lower variation in ceramic shape was identified after the European presence and even much lower variation during the Chinese presence. The direct relationship between foreign influences and highly standardized ceramic shape was tested here on Kiwulan pottery. This finding helps to understand the cause and factor that would lead to the standardization of pottery production in a cross-cultural interaction context. This gave an insight into the discussion of ceramic specialization which is usually associated with the changes in social organization. The more homogeneous shape during the contact period without any changes in clay paste or producing technique suggests that shape standardization is an outcome resulted from an intentional act. The results here suggest an expression of social identity or showing cultural boundary in indigenous societies through visible variable when encountering foreign intrusion. The analysis allows comparisons between sites with a similar historical trajectory in a pericolonial context. Our case study includes an openly available pipeline suitable for other assemblages, ensuring reproducibility and expanding the use of shape-based quantitative methods to questions about craft specialization and standardization in prehistoric technologies.

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### Colophon

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