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 and explain that specialization is a subsistence strategy to accommodate uneven distribute of resources (Arnold and Munns, 1994; Costin, 2001), or a reaction to the changes in subsistence practices (Stark, 1995a). However, the explanation for the emergence of specialized production emerges might not be exclusive or straightforward. Also, specialization is not necessarily accompanied with social differentiation that is observed in lowland northern Philippines with low degree of ceramic specialization during the Spanish colonial period (Acabado et al., 2018). This implies that the condition and contexts under which specialists organized are important for interpretation of changes in social organization (Roux and Karasik, 2018).

The variation of standardization of specialized product is commonly used as indicator to identify craft specialization 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, such as metric, compositional, and technological approaches (Arnold, 2000; Blackman et al., 1993; Costin, 1991; Rice, 1991; Roux, 2015; Tite, 1999). Among those variables, metric measurement is widely applied in archaeological assemblages by calculating coefficient of variation between sets of data coupled with statistical comparison that lower value reflects higher degree of standardization (Eerkens and Bettinger, 2001; Roux, 2003; Stark, 1995b). However, this traditional typological and linear measurements might be limited because they can be insensitive to subtle variations resulting from changes in assembles. 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). Taking geometric morphomerics approaches to the measurement of craft specialization, we study shape and standardization of locally made ceramic to identify changes in ceramic production in cross-cultural interaction contexts at Kiwulan (1350-1950 AD), a large multi-component archaeological site in northeastern Taiwan. The aim of this paper is to investigate if there are increasing ceracmic specialization resulting from interaction with the Europeans and the Chinese, two major foreign influences in early historical Taiwan that might indicate social changes in the indigenous society.

## Geometric Morphometric approach: shape analysis for ceramic specialization

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 the shapes (Adams et al., 2004; Bookstein, 1997; Lawing and Polly, 2010; Slice, 2007). Landmarks, curves or outlines of objects can be represented by coordinates by their unique point location with respect to numerical values of coordinate axes. According to different focuses and nature of original shape data, there are two common morphometric methods used to capture and analyze the shapes, 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 is widely used for archaeological objects where a morphological signature is obvious to identity which provides 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-based morphometrics is that landmark data may not be able to capture the shape differences of a morphological structure where the curving outlines between landmarks convey important information. In addition, obvious and reliable landmark points may be unavailable for complex or rounded shaped structures. In those cases, outline approaches serve as a solution by analyzing the overall shape of a morphological structure. 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) commonly used for two-dimensional closed shape which turns coordinates into coefficients (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). The application of EFA in archaeology is mostly used for bone morphology to understand the biological variation and recently more for stone artifacts to explore stone tool technology (Fox, 2015; Hoggard et al., 2019; Ioviţă, 2010). Outline approach based on EFA is suitable for shapes lacking obvious landmarks or curves convey more important information indicating the meaningful variations, for example, ceramics. Wilczek et al. (2014) evaluate the concordance between outline-based approaches, the EFA and the Discrete Cosine Transform (DCT), and traditional typology by studying 154 complete ceramic vessels with varied shapes from the Bibracte oppidum in France. They found that the variation in ceramic shapes analyzed by EFA and DCT matches traditional ceramic typology, which supports that outline-based approaches can be efficiently used for studying variations in ceramic shapes. In addition, the results of shape variation by EFA helps to understand the level of production standardization over time across that region.

## social changes in cross-cultural interaction contexts

* here I have the third cultural resistance, identity take a look at social boundary
* hypothesis, goals

Culture contact between indigenous people and colonizer with imperial power usually leads to profound changes in local indigenous societies. We explore the culture changes in indigenous societies in northeastern Taiwan that experienced foreign interactions with the Europeans and Chinese since 17th century by examining the local pottery production. We observed ceramic production in northeastern Taiwan in the late Iron Age period and historical period (1400-1900 AD) presenting a high consistency in form and shape compared to other pottery found from other regions on this island that hints the emergence of pottery specialization. Our aim is to explore the impact of foreign contacts on local indigenous societies in northeastern Taiwan by examining pottery production as an indicator for social changes. Using pottery shape as a proxy to study craft specialization, we answer these questions: Did foreign contacts have impacts on indigenous pottery production that can be detected in the shape of the vessels? How does pottery change in shape throughout 600 years at this site? Did pottery become more homogeneous and standardized in shape after foreign contacts with the European colonizer or the Chinese immigrant?

Our hypothesis is that if foreign contacts including European and Chinese had impact 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. The emergence of craft specialization, here pottery specialization, are usually related to the presence of elite control. In this case, if the competitions for foreign resources and being trade partners of European or Chinese colonizer among individuals gradually lead to the emergence of social inequality, then we expect the local pottery will show more homogeneous features after contact due to the craft specialization caused by control of small group of individuals. The first step is to detecting pottery standardization when discussing the emergence of craft specialization and the possible changes in social organization. This paper uses Elliptic Fourier Analysis, one outline approach in Geometric morphometric methods, to test whether there was increasing pottery standardization in relation to foreign contacts.

In this paper, we use EFA for pottery shape analysis to evaluate the level of standardization of pottery from an Iron Age site in northeastern Taiwan in relation to the European presence in the 17th century that might hint the emergence of craft specialization for pottery production. Craft specialization can provide further evidence about the type of production organization which is closely related to economic or political aspects of society (Arnold, 2000; Blackman et al., 1993; Costin, 1991; Hirshman et al., 2010; Stark, 1995b). The emergence of craft specialization can also be an indicator of social inequality that hints the possibility of the presence of production groups worked for specific individuals. The presence of craft specialization is commonly studied by measuring the standardization of ceramics based on the assumption that the specialized mass production will lead to uniformity or homogeneity of the product due to increased skills, routinization, and lower diversity of producers (Arnold, 2000). To test the prediction of a shift in the level of social inequality in this case study in northeastern Taiwan influenced by the colonial European presence, we use standardization of pottery in shapes as an index for craft specialization to identify the presence of a few individuals controlling large scale pottery production (Costin and Hagstrum, 1995; Hirshman et al., 2010) using outline-based geometric morphometrics couples with traditional metric measurements to compare and evaluate the use of outline approaches for pottery with high consistency in shapes.

* craft or pottery specialization
* CV is hard to test, we apply some statistics testing for it, - innovative: CV test

# Materials

## Archaeological background

Ceramics analyzed in this paper come from 40 units (4m by 4m) sampled from 4 connected trenches at Kiwulan, northeastern Taiwan. 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 and mountains on three other sides. The chronology of Kiwulan can be divided into two cultural components, the upper and the lower component, with a sterile layer in between (Chen, 2007). This paper focuses on the upper component dating from AD 1350 to AD 1950, which covers 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 was founded by Koxinga, a loyalist of the Ming dynasty of China (Andrade, 2007).

The upper component experienced frequent foreign contacts including the European colonial presence in the 17th century and great waves of Chinese immigrants since the 19th century. The excavation revealed abundant artifacts in which potsherds are the dominate materials throughout the site. Imported ceramics from mainland China, stonewares, and ornaments elements such as beads were also commonly found in the upper component that indicates the frequent long-distance trade activities in the 17th century during the European presence. In addition to artifacts, features were also found, such as burials, middens, and post-holes with in-situ posts that explain Kiwulan was a large settlement site (Chen, 2007). The predominant artefact found at Kiwulan is locally made ceramics, which distributed throughout the sequence across the site.

More than 550 thousands of sherds were excavated from the upper component at Kiwulan, and around 1,200 vessels were reconstructed. It is interesting to note that there are only two forms of vessels recovered, one is cooking pot and another one is steamer made of two cooking pots stacked together with a filter in between. Those pots show high consistency in shape - 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 because of the evidence of charred residues or carbon deposits commonly observed on the interior and soot on the exterior. Besides, there is no other utilitarian earthenware ceramics found at this site suggests this type of pot was mainly used for daily cooking. Most pots 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.

We examine 291 pots recovered from Kiwulan site. The layer from 1 to 6 could be divided into 3 time periods. Layer 5 and 6 represent pre-contact period, layer 4 represents contact period, and layer1, 2, and 3 represent post-contact period. The amount of pots for each layer shows below. Although most pots are not complete, the thickness from rim, neck, to body can be measured. I have also measured the diameter of the rim, neck, and body. For those pots that are incomplete, the diameter is measured by its curvature. Since the height is incomplete for most pots, this preliminary analysis focuses more on the possible change in thickness and diameter of pot for different parts, and their ratio over time.

Petrographic analysis for thin sections was conducted at the Department of Geosciences, National Taiwan University. The results show 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). Overall, this type presents a mixture of fine, rounded argillite with a small part of rounded metasandstone and rounded to sub-angular monocrystalline quartz. Those minerals are believed to be local materials of the Yilan Plain.

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 this study because of their completeness mostly covering parts from rim to bottom.

# Methods

## 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

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 with the mean of the standardized Fourier coefficients within each phase group (Figure 1).

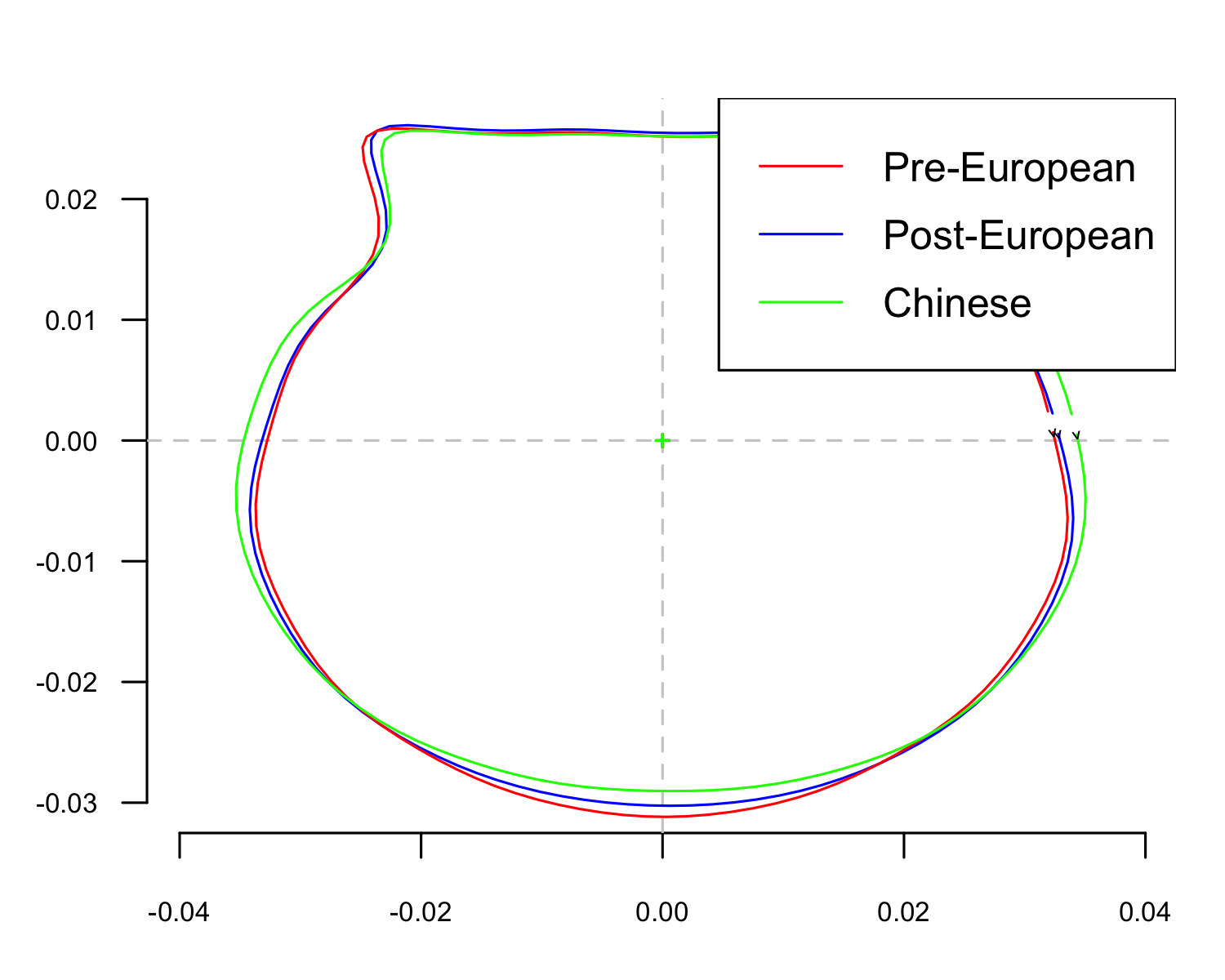
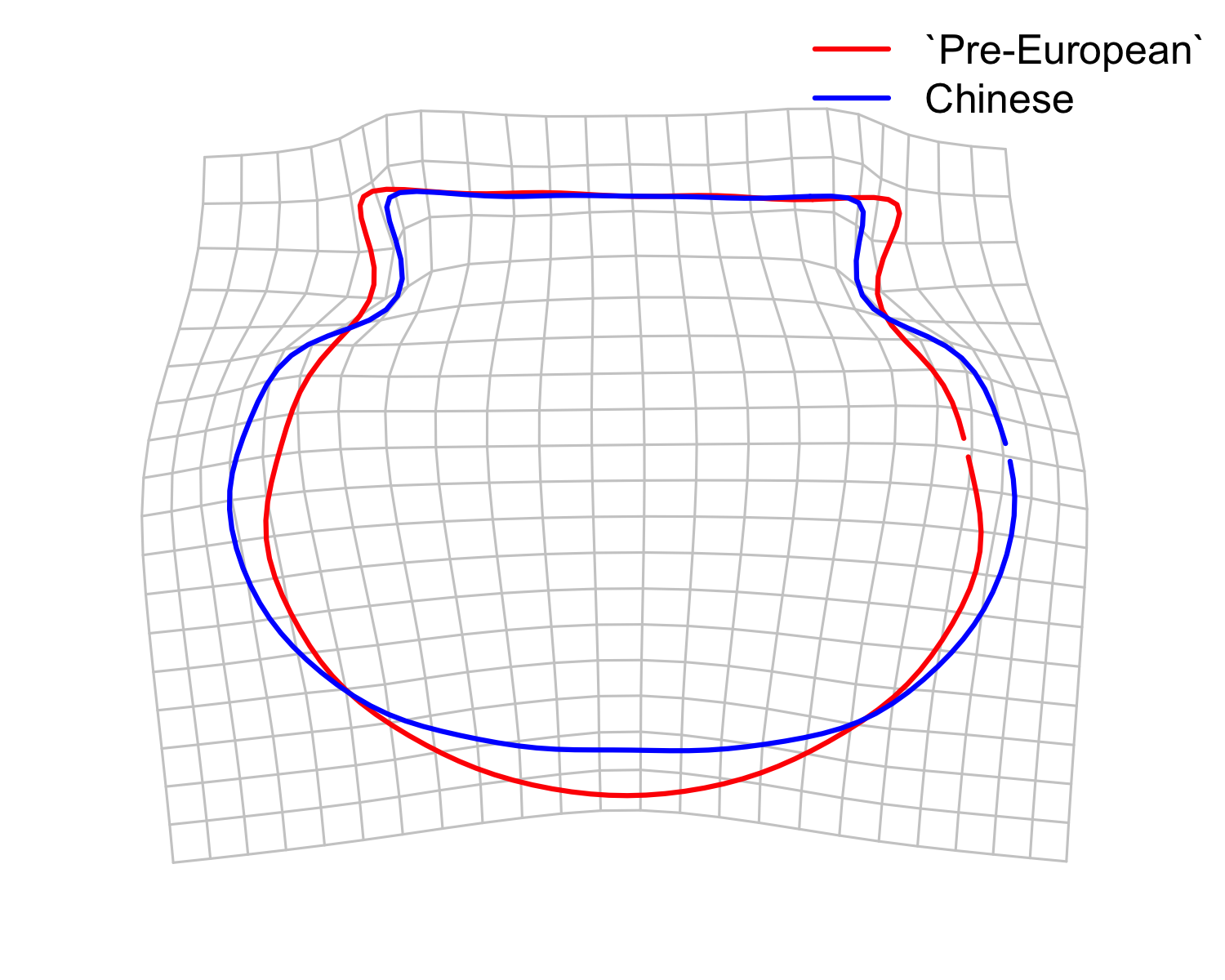
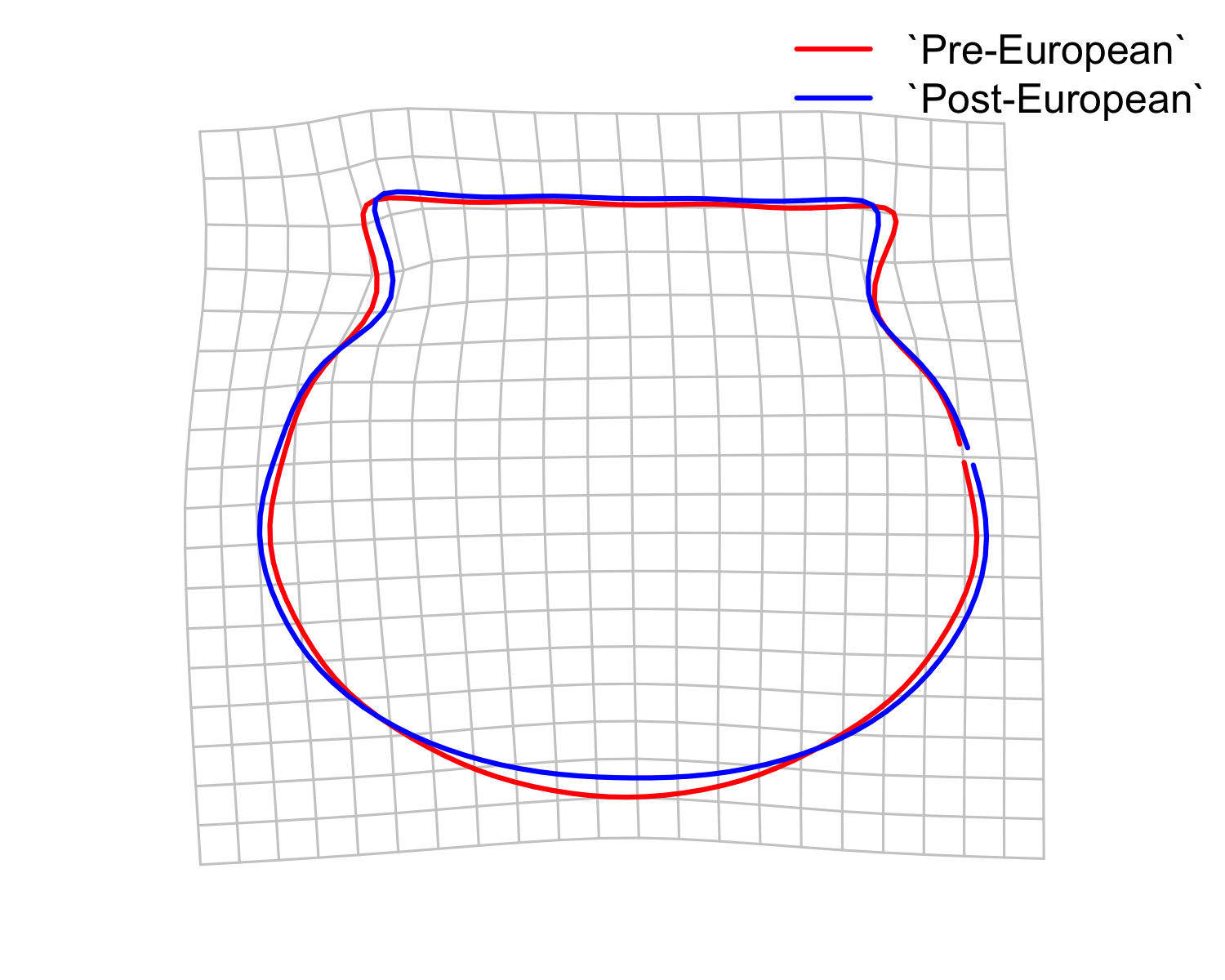
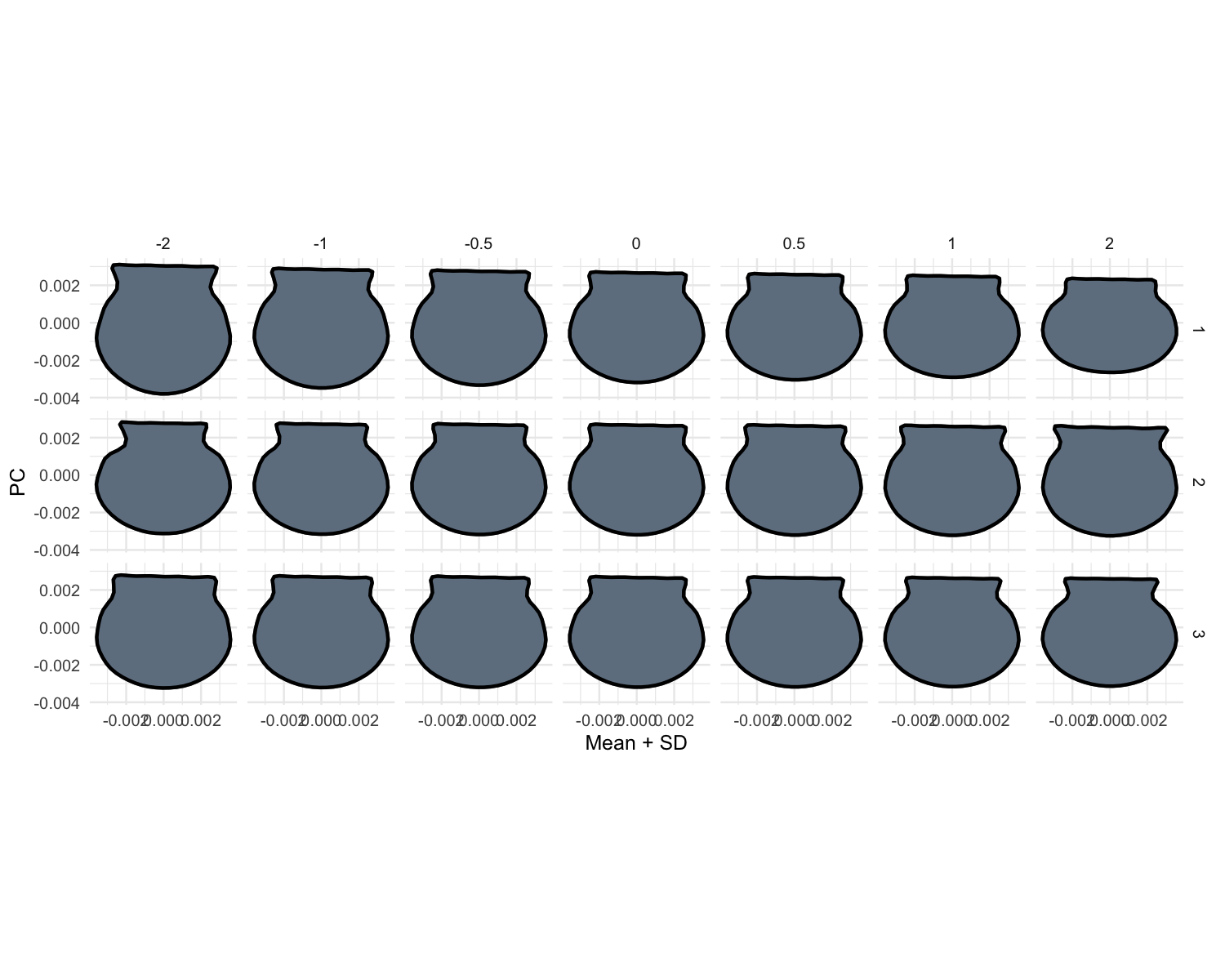
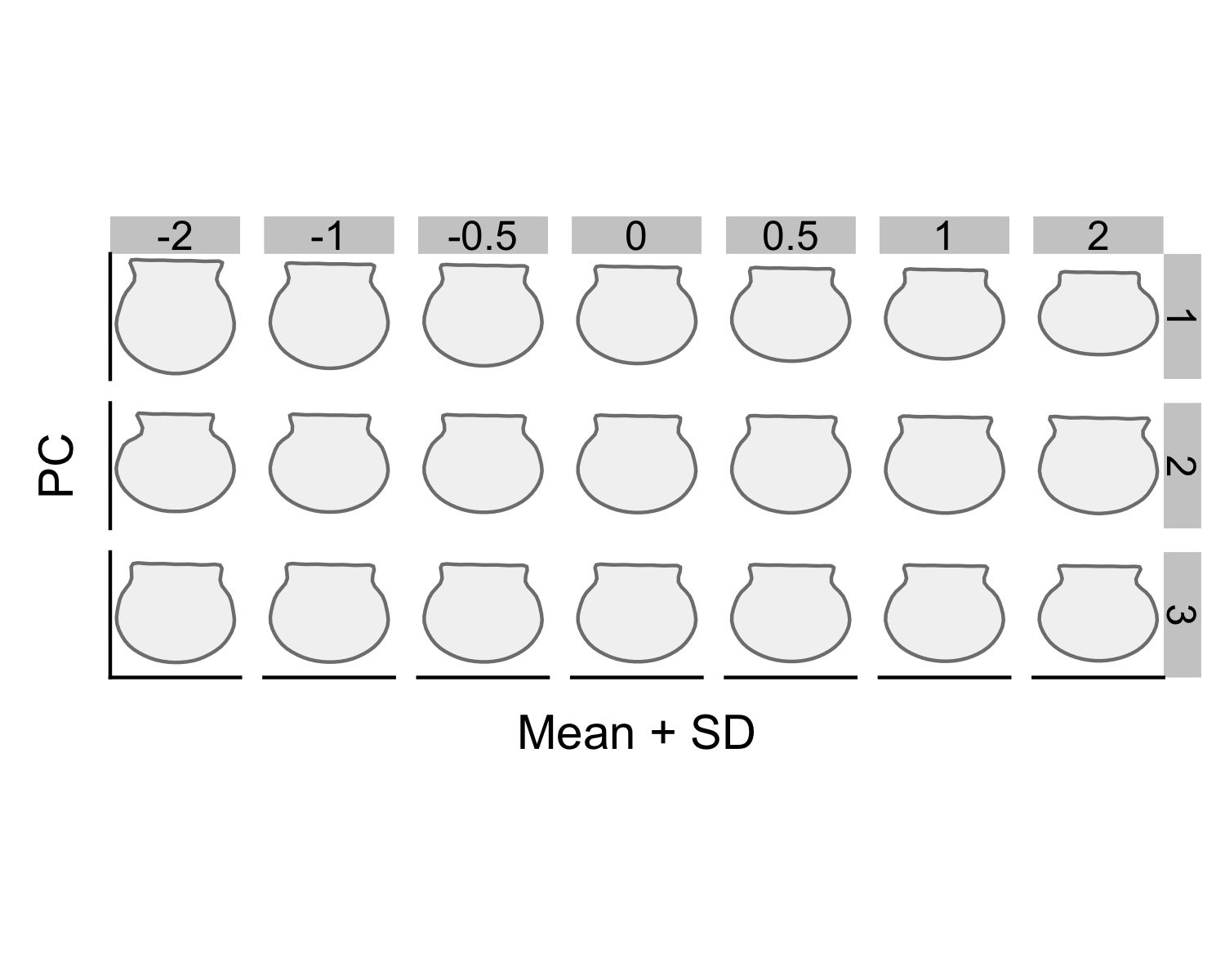


Figure 1: Mean pottery shapes of three phases



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 ?? 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 4. 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.



#> quartz\_off\_screen   
#> 2

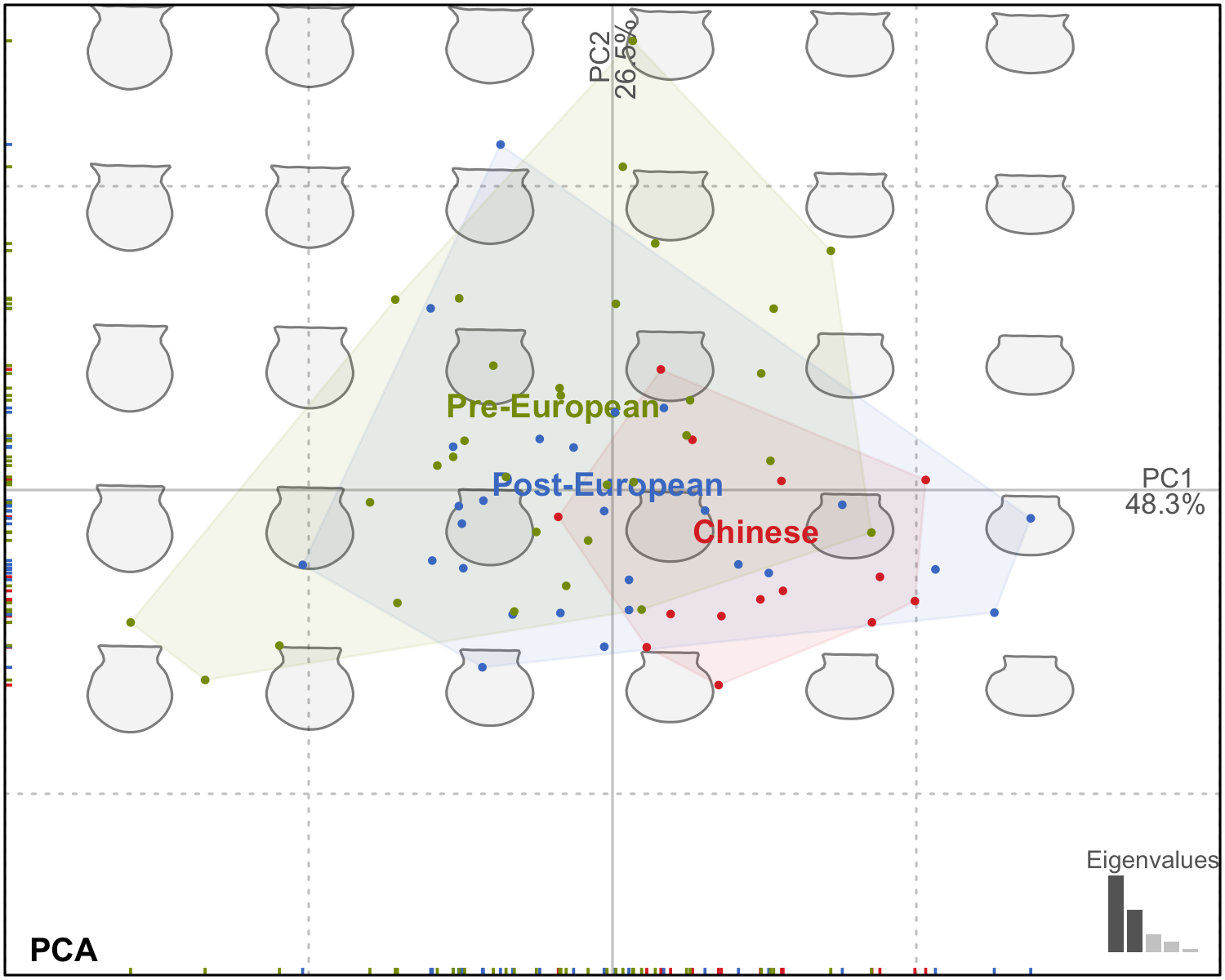


Figure 4: Pottery shape distribution by each occupation phase according to the first two PCs

#> $stars.tab  
#> Chinese Post-European Pre-European  
#> Chinese - \*\*\*   
#> Post-European \*   
#>   
#> $summary (see also $manovas)  
#> Df Pillai approx F num Df den Df Pr(>F)  
#> Chinese - Post-European 1 0.3806 1.620 11 29 1.452e-01  
#> Chinese - Pre-European 1 0.6942 7.018 11 34 4.951e-06  
#> Post-European - Pre-European 1 0.3491 2.292 11 47 2.434e-02

Table 1: The statistics summary of MANOVA test for the PC scores

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Df | Pillai | approx F | num Df | den Df | Pr(>F) |
| Chinese - Post-European | 1 | 0.3806357 | 1.620200 | 11 | 29 | 0.1451623 |
| Chinese - Pre-European | 1 | 0.6942310 | 7.017731 | 11 | 34 | 0.0000050 |
| Post-European - Pre-European | 1 | 0.3491049 | 2.291660 | 11 | 47 | 0.0243367 |

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 1 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.

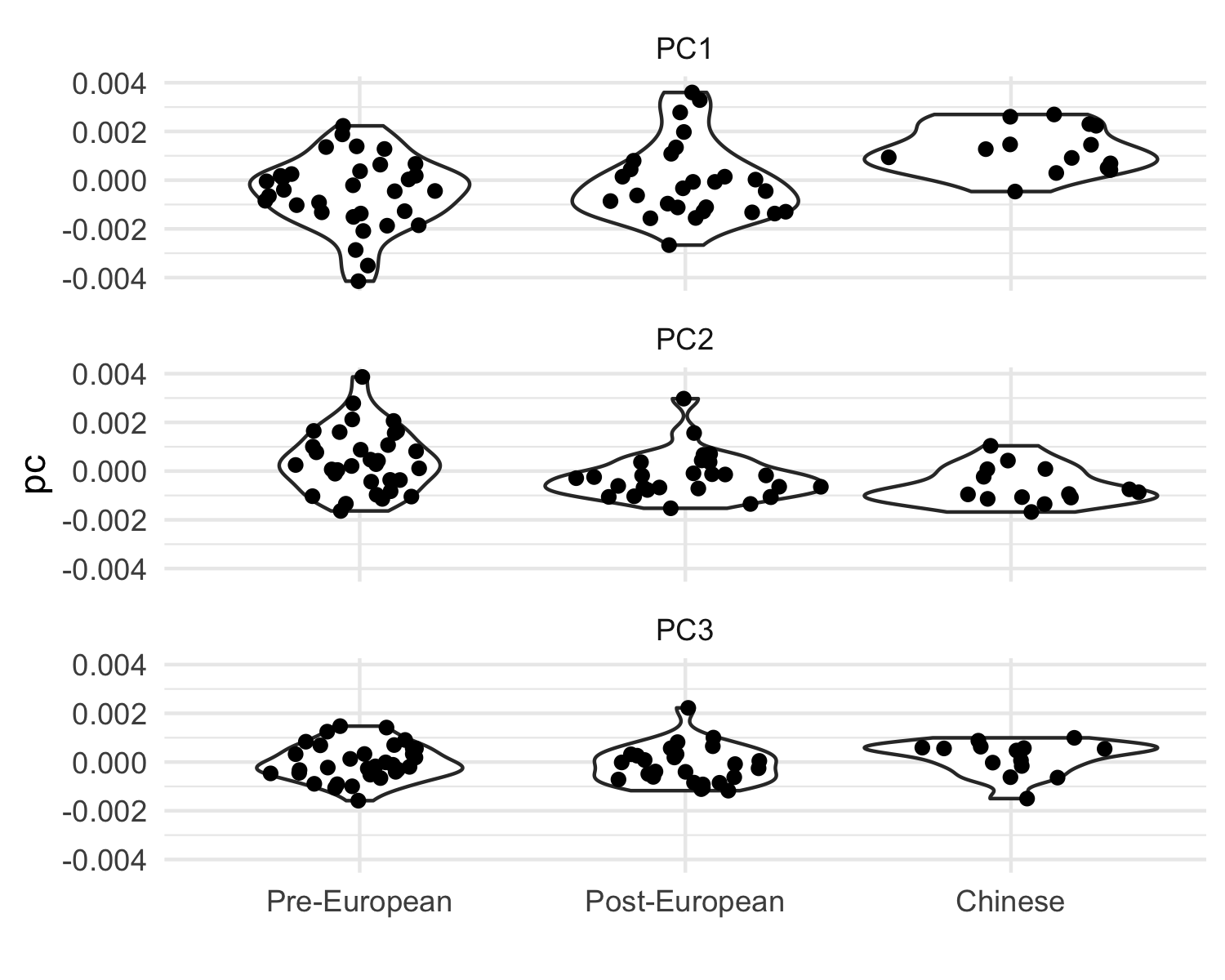


Figure 5: The distribution of PC scores by phases

#> # A tibble: 9 x 3  
#> # Groups: pcn [3]  
#> pcn phase variance  
#> <glue> <fct> <dbl>  
#> 1 PC1 Pre-European 0.00000216   
#> 2 PC1 Post-European 0.00000242   
#> 3 PC1 Chinese 0.000000902  
#> 4 PC2 Pre-European 0.00000162   
#> 5 PC2 Post-European 0.000000902  
#> 6 PC2 Chinese 0.000000587  
#> 7 PC3 Pre-European 0.000000553  
#> 8 PC3 Post-European 0.000000604  
#> 9 PC3 Chinese 0.000000487

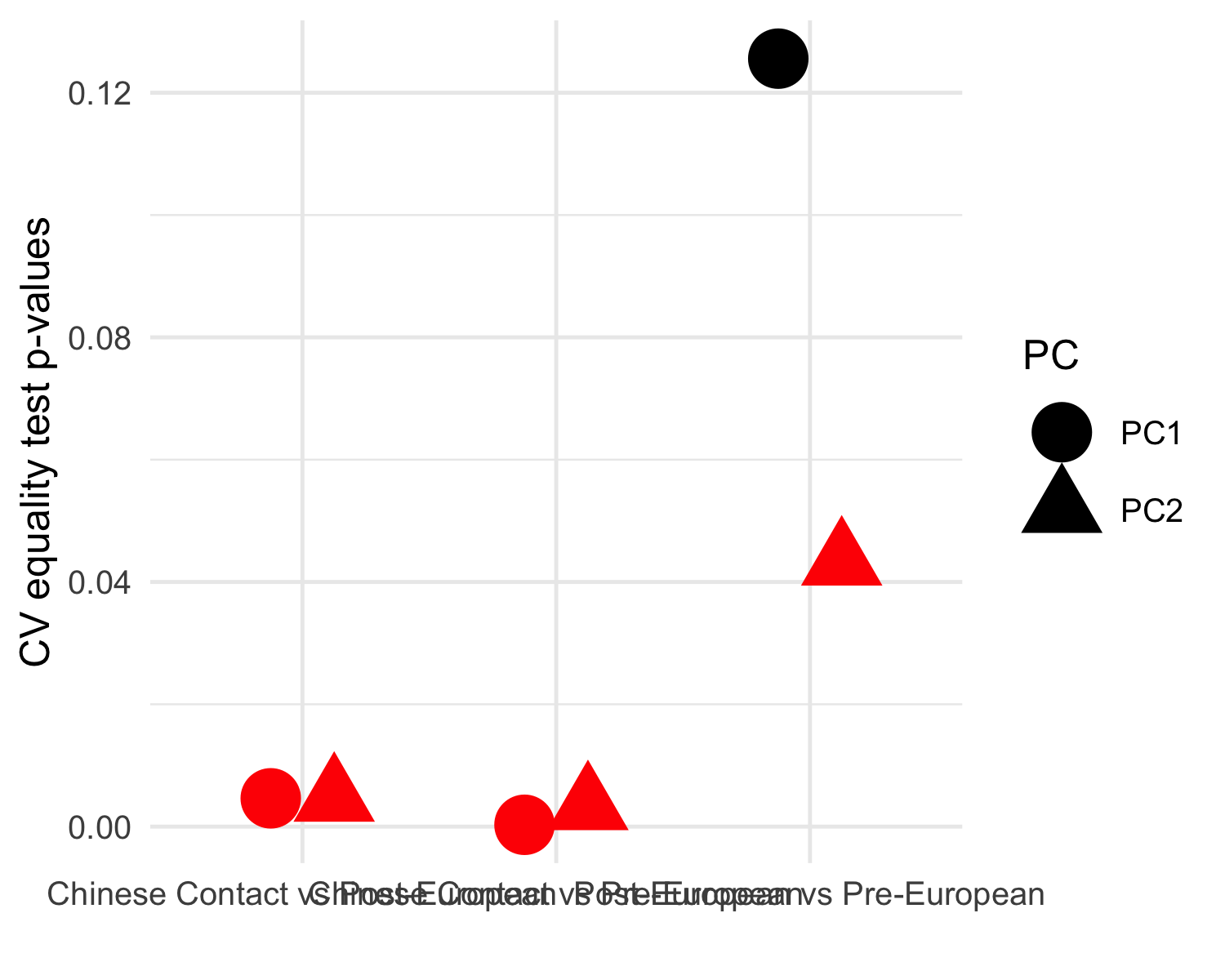


Figure 6: P-values of the CV equality test of PC1 and PC2 between phases, red color indicates p-value is less than 0.05

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 5 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 < 0.01) in the standardization of vessel shape across some periods, especially between Chinese contact with either pre-European or post-European Figure 6.

# Discussion

The results confirm that the differences in pottery shapes can be detected using outline analysis approaches. It shows there is differences in pottery shapes between pre-European and post-European, and Pre-European and Chinese contact. A increasing standardization of shape of pottery during the Chinese contact period compared to the other two periods is observed. This study provide an comparable basis for our understanding of the standardized pottery as an indicator of social changes in a cultural contact conditions. Northeastern Taiwan had been encountered two major foreign contacts in the 17th century with the Europeans and 19th century with the Chines immigrants. It shows that the standardization of pottery shape appears during the European presence and increased in the Chinese period. This may suggest that an emergence of specialized groups or a consensus of the adoption of similar shape of pottery in the society. The changes in the standardization of pottery may indicate a major social changes in the local indigenous organization. When it comes to ceramic specialization, metric measurements and clay paste are two major indicators. Shape analysis could be viewed as a replacement of metric measurement that enables subtle changes to be detected. We observe the increasing standardization of the pottery shape, however, it is interesting to note that there is no obvious changes in the clay paste across different phases.

# Conclusion

We find differences in shape and shape standardization of pottery that indicate changes in pottery production resulting from foreign contact, suggesting increasing craft specialization and changes in local social organization at Kiwulan. These results are important to understand the influence of culture contact on local indigenous societies and answer the anthropological question that concerns the the mechanisms for social changes. In addition, our case study, which includes an openly available research compendium of R code suitable for use with any other assemblage, will help to expand the use of shape-based quantitative methods to questions about craft specialization and standardization in prehistoric technologies.

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##### pagebreak

### Colophon

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#> Head: [756d244] 2020-01-02: updates for introduction

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