Standardization of ceramic shape: A case studay from the Iron Age pottery from northeastern Taiwan

Li-Ying Wang

Ben Marwick

24 July, 2020

The emergence of ceramic specialization in prehistoric societies is often linked to shifts in the complexity of social structures, because standardized ceramic 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 useful 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 northeastern 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 northeastern Taiwan. 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.

# Introduction

A major historical factor often linked to social change in small-scale societies is the introduction of foreign or exotic trade goods to local Indigenous societies (Mullins, 2011). Monopolization of long-distance trade goods has caused substantial transformations in Indigenous economic, cultural, and socio-political systems (Dietler, 2005, 1997; Junker, 1993; Silliman, 2005). Pericolonial archaeology is the study of these indirect effects of colonialism, investigating areas where direct European colonial rule was limited, their conquests were often short-lived and unsuccessful, but commercial activities yielded economic and political impacts on Indigenous peoples living on the periphery of colonial control (Acabado, 2017; Trabert, 2017). Pericolonial situations were common during the seventeenth to nineteenth centuries in East and Southeast Asia where European trading activity was extensive, but direct European rule less widespread. An emerging priority in archaeological research in Asia is identifying the indirect influences are apparent on Indigenous communities during the colonial period. For example, Acabado (2017)’s study of Ifugao society in the Philippines highland suggests economic and political intensification during the Spanish presence in the lowlands as a strategy of Indigenous peoples to resist Spanish conquests.

Indigenous societies’ responses to colonial contact ranges from passive acceptance to active negotiation with the colonists, and accommodation or resistance of foreign intrusion, which can be identified through their daily cultural practices, such as their consumption patterns of foreign goods (Dietler, 2015; Given, 2004; Mullins, 2011; Scaramelli and Scaramelli, 2005; Silliman, 2001; Torrence and Clarke, 2000). In this paper we investigate the archaeology of a pericolonial situation at Kiwulan (ca. AD 1350-1850), a large multi-component archaeological site in Yilan County, northeastern Taiwan (Chen, 2007), to identify the indirect impacts of colonial settler activity on local Indigenous societies. Yilan is an ideal context to study peripheral colonial influences because the Indigenous communities were isolated by geographical barriers, limiting the frequency of direct contact with the Spanish and the Dutch settlers in northern Taiwan. Kiwulan is situated on a hill near a riverside at the northern margin of Yilan County, which is characterized by a triangular alluvial plain facing east toward the Pacific with high mountains on three other sides.

This research investigates if there was increasing ceramic specialization resulting from Indigenous interaction with Europeans in the 17th century or Chinese in the 19th century, two major foreign influences in early historical Taiwan, which may indicate social changes in local Indigenous societies. We predict that competition within the Indigenous community at Kiwulan for foreign resources and trade partnerships with European or Chinese colonizers may have led to the emergence of craft specialization caused by greater economic and social control of ceramic production by a small group of individuals. Using standardization in ceramic shapes as a proxy for craft specialization, we ask: Did colonial trade impact the shape of locally-produced Indigenous pottery vessels? Did pottery shape become more homogeneous and standardized after foreign contacts with European colonizers or Chinese immigrants?

Several measurements have been used for investigating ceramic standardization that include metric, compositional, and technological variables (Arnold, 2000; Blackman et al., 1993; Boness et al., 2015; Costin, 1991; Rice, 1991; Roux, 2015; Tite, 1999). Among those variables, metric measurements are most widely applied to archaeological assemblages. The coefficient of variation (CV) statistic is regularly used to quantify the degree of standardization in ceramic assemblages (Eerkens and Bettinger, 2001; Junker, 1999; Roux, 2003; Stark, 1995). However, because pottery vessels typically have curved shapes, linear measurements have limited sensitivity to many kinds of shape variations. Thus, to capture subtle shape variations that might also be relevant to standardization, we analyze ceramic shapes using geometric morphometric methods (GMM).

## Geometric Morphometrics

Geometric morphometrics differs from traditional linear measurements through its use of Cartesian coordinates of morphological structures to quantify and analyze shape (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 on coordinate axes. There are two common morphometric methods: landmark and outline approaches (Adams et al., 2004). Landmark GMM approaches assign a set of landmarks and/or semilandmarks onto objects as reference points that can be specified on a coordinate system. Landmark-based morphometrics are widely applied to archaeological objects with obvious morphological features that provide unambiguous reference points for landmark placement, such as tips and edges of stone tools or iron weapons (Birch and Martinón-Torres, 2019; Lycett and Cramon-Taubadel, 2013), visually distinctive bone features (Haruda et al., 2019; Meloro et al., 2015), or ceramic assemblages with clear distinct components (Selden Jr, 2019; Topi et al., 2017). With univariate or multivariate statistics for shape data generated by GMM, the application to artifacts can answer research questions related to topological evolution or variations in assemblages to define groups (**???**; Doyon, 2019; Eren et al., 2015; Perez, 2007; Selden et al., 2018). A common procedure is using dimensional reduction techniques, such as principal components analysis or canonical variate analysis, to capture the essential features that can represent the overall shape. This enables the identification of clustered analytical groups through the visualization of results, followed by statistical tests to robustly distinguish them.

One of the interesting topics is to explore whether and why there is shape standardization over time, or between assemblages across geographical areas. It is common to use multivariate analysis on shape variables or coefficient of variations on associated metric data to discuss standardization, especially for lithic assemblages. For example, Archer et al. (2015)’s case study of stone points in Southern Africa suggests an increase in shape standardization over time that may relate to a maintenance of finished points. With considerations of a set of metric data, Buchanan et al. (2018); Buchanan et al. (2019) identified a more uniform base-shape of Folsom points than Clovis points across the western US, which indicates the specific function for hafting. Similarly, Smith and DeWitt (2016) suggested that the humongous fluted point base in Alaska and northern Yukon is a risk management strategy to ensure the ease of replacement during long-distance travel. Other factor, such as low level of cultural innovation in a small group could also lead to an increase in standardization of point shapes (Okumura and Araujo, 2014). For ceramics, Topi et al. (2017) found a standardized vessel shape from the Casas Grandes culture in northwest Mexico using coefficient of variations for the positions of semi-landmarks across shape groups. They suggest the standardization might indicate the pretense of specialized producers reflecting social complexity. Another way to examine standardization is using morphological disparity to perform pairwise comparison of correlations between shape groups (Wills, 2001). In this manner, Selden Jr (2018); Selden Jr (2019) examined Caddo ceramics in northeast Texas region and found a gradual shape standardization over time that provides a basis for further discussion of craft specialization or group identity. Similar applications to bifaces in central Texas presented the evidence of grater diversity in morphology (Selden Jr et al., 2020). More other applications, such as cranial deformation, demonstrate that landmark approach with multivariate analyses on shape variances or symmetry is an effective method to evaluate shape standardization (Kuzminsky et al., 2016; Natahi et al., 2019; Perez, 2007).

Despite the wide use of landmark approach in archaeology, a key limitation is that landmarks may be difficult to reproducibly locate for structures that are mostly or entirely curves if not mathematically-defined. In those cases, outline approach, such as Elliptic Fourier Analysis (EFA), is a better mean for assessing morphological variation in whole structure of two-dimensional closed shapes (Cardillo, 2010). EFA uses periodic functions to capture geometric information, where an outline is decomposed into a series of ellipses described by trigonometric functions (Adams et al., 2004; Bonhomme et al., 2014; Claude, 2008). To be specific, EFA converts coordinates along a curve into Fourier function coefficients, called harmonic coefficients or harmonics (Kuhl and Giardina, 1982). The number of harmonics determines the quality and precision of the geometric representation of an object. The harmonic power, a cumulative sum of squared harmonic coefficients, provides a robust rule for determining the desired number of harmonics (Bonhomme et al., 2014). The first systematic use of EFA in archaeology was Gero and Mazzullo (1984)’s study of lithic flakes in Peru that suggests the changes in forms from a more angular to rounded shape over time. Later, Saragusti et al. (2005) introduced several functions for the further calculation of the specific shape attributes, including symmetry, roughness, and deformation, which demonstrates the potential for analysis of curves. To compare resharpening trajectories in the European Middle Paleolithic stone tools, Ioviţă (2009) presented a protocol from outline digitization to EFA, with considerations of size using multivariate linear regression. More recent applications to stone artifacts seek to answer questions about topological classification of Late Woodland points (Fox, 2015), cultural taxonomies for the European Late Palaeolithic (Ivanovaitė et al., 2020), and shape and symmetry standardization of British Acheulean (Hoggard et al., 2019).

The EFA applications for ceramics is rare, however, this approach is promising for answering questions related to ceramic taxonomy and standardization. For example, Wilczek et al. (2014) evaluate the concordance between EFA and Discrete Cosine Transform (DCT), and a 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 the traditional ceramic typology, which supports that claim that outline-based approaches can be efficiently used for studying variations in ceramic shapes. Furthermore, Wilczek et al. (2014)’s EFA results help us understand the level of production standardization over time across the region. EFA is suitable for analyzing shapes lacking representative landmarks, or where curves contain the most meaningful variation. In such cases, the focus is the whole shape instead of the different components of a shape. We use EFA to evaluate the level of standardization of ceramics data from Kiwulan, northeastern Taiwan, in relation to the European presence in the 17th century to gain insights into the emergence of ceramic specialization. The reason of using EFA is because there is no sufficient landmarks could be identified straightforwardly due to the globular body of ceramics. We use a significance test for the equality of coefficient of variations of shape variables to statistically compare the vessel standardization from different periods.

# Archaeological background and materials

Ceramics analyzed in this study come from 40 units (4m by 4m each) sampled from the central, undisturbed area of archaeological excavations at Kiwulan (Figure 1; Figure 2). The chronology of the archaeological deposits consist of two cultural components, the upper and the lower, with a sterile layer in between (Chen, 2007). We focus on the upper component, dated from AD 1350 to 1850, spans the late Iron Age and the historical period, of which the start is defined as the European occupation in Taiwan in the early 17th century. The Dutch first occupied southern Taiwan in 1624, followed by the Spanish in northern Taiwan in 1626 (Andrade, 2007). In 1642, the Spanish was expelled by the Dutch, who then occupied the previous Spanish forts at Helping Dau in Keelung, and in Tamsui. Western Taiwan remained under Dutch colonial rule until 1662 when the Kingdom of Tungning in Taiwan was founded by Koxinga, a loyalist of the Ming dynasty of China (Andrade, 2007).



Figure 1: Map illustrating the location of Kiwulan, and other locations in northern Taiwan that are named in the text. Map data is 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

The archaeological record of Kiwulan’s upper component shows traces of foreign contact, including Europeans in the 17th century, and waves of Chinese immigrants in the 19th century. Imported ceramics from mainland China, stoneware, and ornaments such as beads have been recovered in the upper component, indicating frequent long-distance trade activities with Europeans and Chinese merchants. Archaeological features such as burials, middens, and post-holes with *in-situ* posts are widespread across the 1-2 m thick deposit of the upper component, and demonstrate that Kiwulan was a continuously occupied large settlement site (Chen, 2007). To compare different foreign influences, we classified the upper component into three chronological phases: pre-European, European, and Chinese. We identified these phases based on 32 previously published radiocarbon ages (Chen, 2007), excavation depth measurements, stratigraphic details reported by the excavators (color, texture, disturbance, etc.), and finds of chronologically diagnostic artifacts, such as blue and white porcelains, light grey glazed jars, and large dark brown glazed stoneware jars commonly used in the 17th century, and bricks and tiles employed by the Chinese in the 19th century (Chen, 2007; Hsieh, 2009; Wang, 2011). The deposit exhibited signs of continuous human occupation in each of the three phases with no apparent breaks.

The most abundant artifacts in the upper component are locally manufactured ceramics, which are distributed throughout the temporal sequence, and across the study site. More than 550,000 sherds were excavated, and around 1,200 vessels could be partially reconstructed (i.e. complete rim or base). There are two shapes of locally-manufactured vessels; a cooking pot and a steamer made of two cooking pots stacked together with a clay filter between. Those vessel shapes demonstrate suites of standard morphological components. Each has a globular body with a short neck and wide mouth (Figure 3). The exterior surface below the neck is decorated with a variety of impressed geometric motifs. These vessels were potentially used for cooking indicated by evidence of charred residues and carbon deposits frequently observed on vessel interiors, and soot on vessel exteriors. Firing resulted in orange and brownish color with a fully oxidized core, or a reduced core with oxidized fringes (Chen, 2007). Finger impressions and seams, usually on the interior, indicate that the vessels were shaped by hand, and that the seems between the slabs were pinched. This kind of vessel has been widely found at archaeological sites during the late Iron Age and the historical period throughout the Yilan Plain (National Musuem of Taiwan History, 2005).

Petrographic analysis for 34 thin sections presents a high percentage of inclusions (15-50%), including argillite (15-40%), metasandstone (1-10%), sandstone fragments (1-6%), quartz (1-5%), and trace amounts of feldspar and slate. Particle sizes of range from 500 to 1300 microns. In general, the globular vessel fabric presents a mixture of fine, rounded argillite with a small amounts of rounded metasandstone and rounded to sub-angular monocrystalline quartz. This composition is consistent with the mineralogical composition of local raw materials found in the Yilan Plain (Chen, 2016). There are no substantial changes in the inclusions over time, indicating continuity in pottery fabric composition across the three periods.



Figure 3: A typical pot from Kiwulan (left) and an example of a pottery drawing used for outline analysis (right)

# Methods

The sample consists of 73 reconstructed vessels with rim, body and base parts, and we securely provenanced to pre-contact (n = 32), post-European (n = 27), and Chinese contact contexts (n = 14).

## Digitizing and analyzing by EFA

We used scans of pottery drawings acquired from the Bureau of Cultural Affairs in Yilan (Figure 3). All drawings provide a two-dimensional view of vessel cross-sections, and metric measurements. The scanned drawings were imported into Inkscape (<http://inkscape.org>) for digitization where outlines were manually traced. In those instances where only one side of the cross-section image was available, these were mirrored and joined to create a closed outline for each vessel. Analyses were conducted in R software (R Core Team, 2019) using functions included in the Momocs package for quantifying and analyzing shapes (Bonhomme et al., 2014). Outlines were converted into a list of successive x, y pixel coordinates for EFA. We analyzed harmonic coefficients by principal component analysis (PCA) for dimensionality reduction to illustrate the diversity of the shape data and identify major patterns of variation.

## Statistical analysis

The principal component (PC) scores were analyzed with a multivariate analysis of variance (MANOVA) test to identify significant differences in shapes between occupation phases. We also computed coefficients of variation values (CVs) for the PCs, treating the PCs as shape variables that are more informative than linear dimensions. 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:

As a standardized measure of the spread of data, coefficients of variation (CV) allows us to directly compare variation in samples measured with different units or means. This is useful to compare the degree of standardization for archaeological assembles and enables comparison of variation across different sample sizes (Eerkens and Bettinger, 2001, p. 498). Following Eerkens and Bettinger (2001) and Roux (2003), we take this as our measurement of standardization in vessel shape variables: lower CV values reflect higher standardization, and thus increased craft specialization in the community. Given that CV is robust for positive values due to the representation by ratio, we normalized PC scores to a range between 0 and 1 before computation of CV.

To answer the question of whether CV values for vessel samples across our three occupational phases are significantly different or not, we used the Modified signed-likelihood ratio (MSLR) test for equality of CVs (Krishnamoorthy and Lee, 2014). While previous work has used the Feltz and Miller (1996)’s asymptotic test for the equality of coefficients of variation from k populations (Eerkens, 2000; Eerkens and Bettinger, 2001; Hoggard, 2017; Lycett and Gowlett, 2008; Okumura and Araujo, 2014), we prefer the MSLR test for shape variables 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 (Krishnamoorthy and Lee, 2014).

To complement our investigation of craft specialization through shape standardization, we investigated spatial patterns of ceramic vessels at Kiwulan. As craft specialization increases, pottery distribution we expect a shift from a pattern of vessels dispersed across the site to a pattern of clusters that reflects the loci of production (Costin, 2001). We used a Monte Carlo test for randomness in spatial locations of pots to explore whether their distribution is significantly clustered or dispersed.

# 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 openly available online at <https://doi.org/10.17605/OSF.IO/ABVGF>. 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

We found that 13 harmonics captured 99% of the total harmonic power in the elliptic Fourier coefficients of 73 vessels from three phases. Figure 4 illustrates significant differences in vessel shapes described using thin-plate spline warping for paired periods, pre- and post-European periods, and post-European and Chinese periods, with the greatest differences between pre-European and Chinese periods.

The first two principal components (PCs) of the PCA on the elliptic Fourier coefficients explain 74.85% of the total variance, of which 48.32% is explained by the first principal component. With the third component, the first three principal components explain 86.08% of the total variance. PC1 captures the height of the vessels, from tall to short, and the roundness of the body from round to oval-shaped (Figure 4). PC2 relates to the neck and mouth constriction, from narrow to wide. PC3 explains a smaller portion of the variance (11.23%), which relates to the degree of the flare in the neck, from a curved to straight shape. The results reflect a large overlap in shapes from three occupations phases, especially for shapes in the pre-European and post-European periods. However, the spread of shape distribution indicates 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, we find a decrease in shape variance in the Chinese period that is evident in the shorter height and narrower mouth of vessels used in that period.

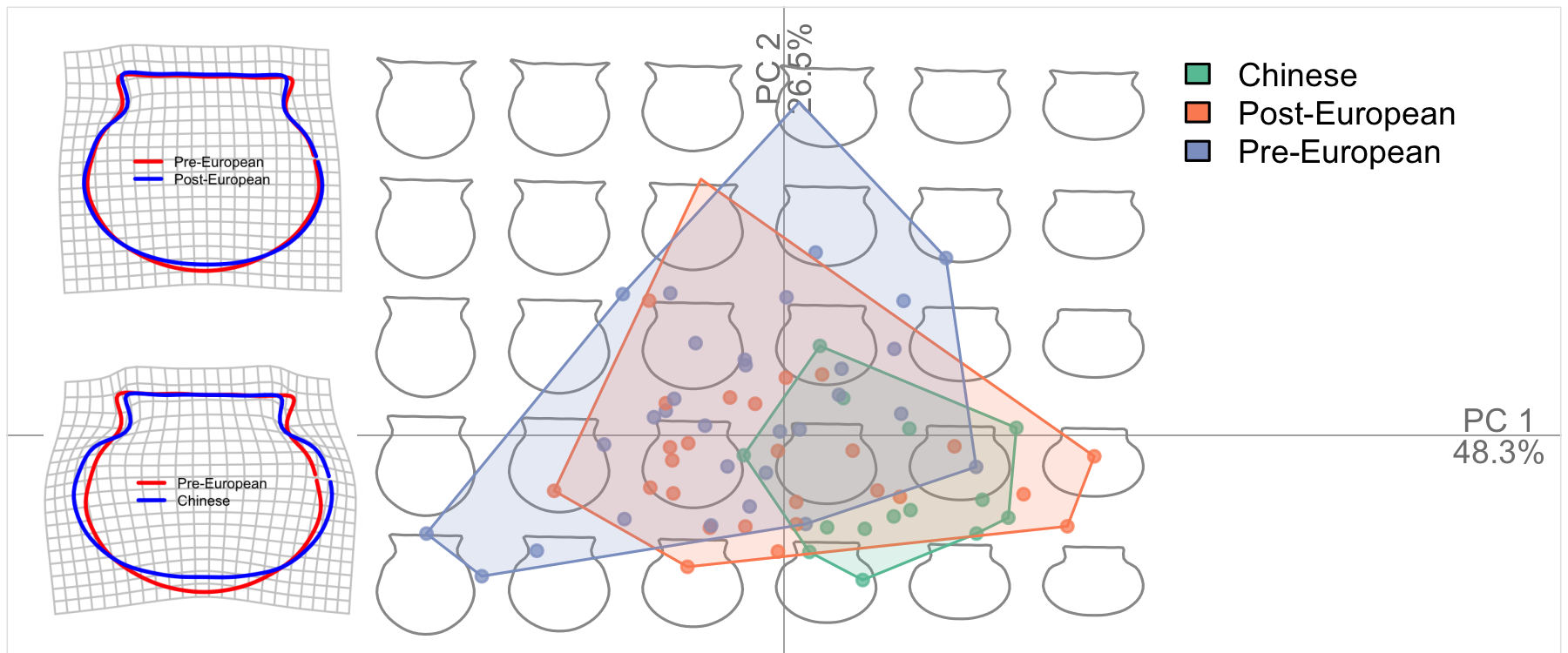


Figure 4: Left: Significant differences in average vessel shapes across phases using thin plate splines (TPS) with outline deformations required to pass from an extreme of one morphospace to another. Right: Pottery shape distribution by each occupation phase according to the first two PCs.

Table 1: Summary statistics for the MANOVA test on the PC scores. Pr(>F) is the p-value associated with the F statistic of the effect and test statistic.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Comparison | Pillai’s trace | Approximate F value | degrees of freedom | Pr(>F) |
| Chinese - Post-European | 0.3806 | 1.6202 | 29 | 0.1452 |
| Chinese - Pre-European | 0.6942 | 7.0177 | 34 | 0.0000 |
| Post-European - Pre-European | 0.3491 | 2.2917 | 47 | 0.0243 |

To test for differences in the distributions of shape variables indicated by the PC scores shown in Figure 4, we used a multivariate analysis of variance (MANOVA) test to compare pairwise combinations across the three occupation phases. Table 1 demonstrated the significant differences in shape between Pre-European and Post-European phases (p = ), and Pre-European and Chinese phases (p = ). These results are consistent with the differences in the visualization of average shapes between the occupations in the thin plate splines (Figure 4, see left). Although there is considerable overlap of shape variables between the Pre-European and Post-European phases, their PC scores differ significantly. There is not a significant difference in vessel shapes between the Post-European and Chinese contact periods.

To compare pottery shape standardization across the three phases we investigate the distributions of the first three PC scores, taking the PC scores as proxy variables for vessel shape (Figure 5). The first PC, capturing vessel height and roundness, shows higher variation in the pre-European period compared to the Chinese period. That indicates that shape standardization was higher in the Chinese period compared to the pre-European period. The second PC also presents a similar pattern of higher shape standardization in the Chinese period compared to the other two phases.

To see whether the differences in the distribution of PCs between any two phases are substantive or due to chance, we used a modified signed-likelihood ratio test to assess the equality of CVs (Krishnamoorthy and Lee, 2014; Marwick and Krishnamoorthy, n.d.). P-values for this significance test of CVs for PC1 and PC2 show significant differences in the standardization of vessel shapes across periods, especially between Chinese contact with either pre-European or post-European (Figure 5, Table 2). A significant difference was also detected between the pre-European and post-European periods.

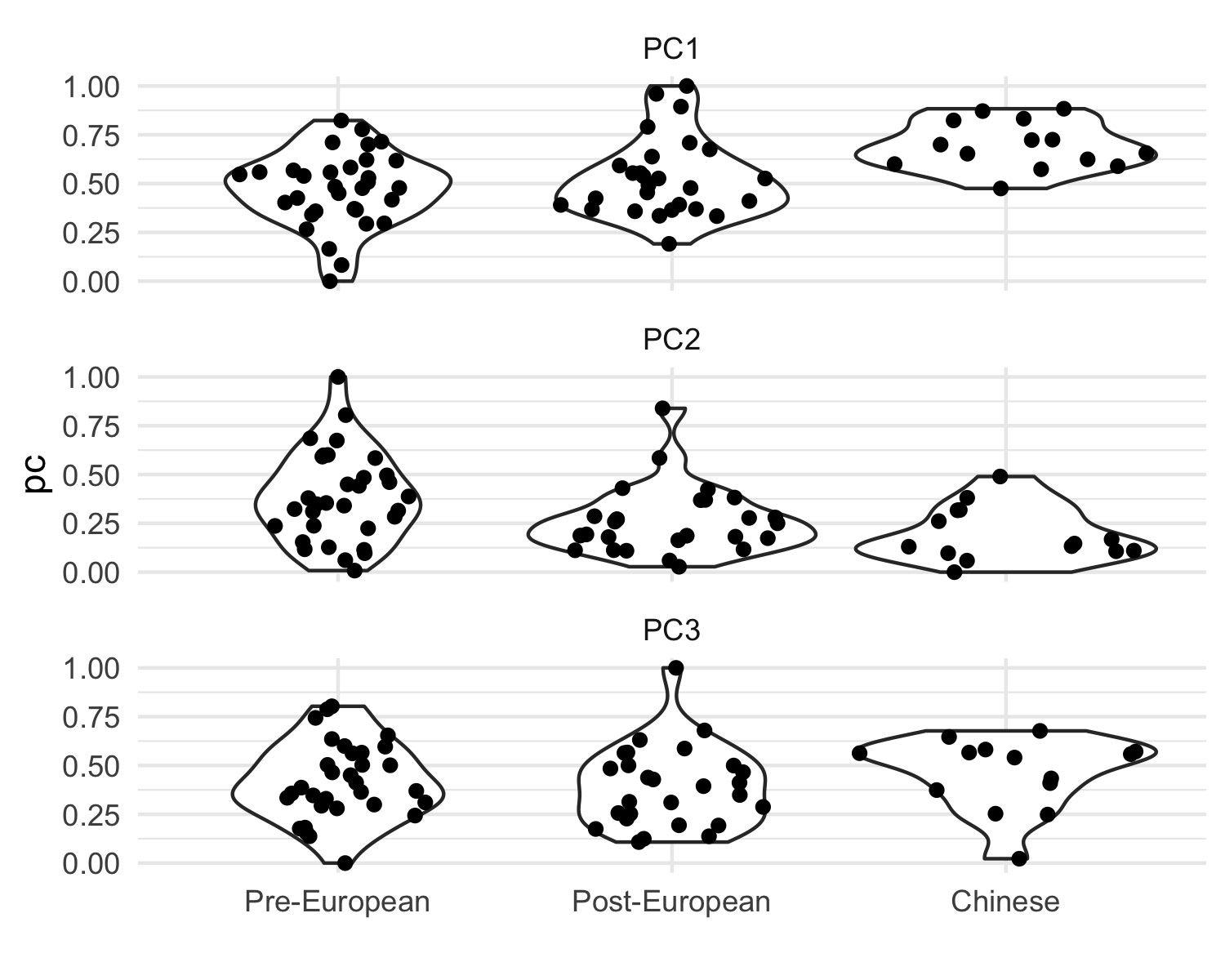


Figure 5: The distribution of PC scores by phases

Table 2: P-values of the CV equality test of PC1 and PC2 between phases

|  |  |  |  |
| --- | --- | --- | --- |
| PC | MSLRT | p\_value | phases |
| PC1 | 0.0374 | 0.8467 | Post-European vs Pre-European |
| PC1 | 8.4473 | 0.0037 | Chinese Contact vs Pre-European |
| PC1 | 7.4192 | 0.0065 | Chinese Contact vs Post-European |
| PC2 | 0.0256 | 0.8729 | Post-European vs Pre-European |
| PC2 | 0.2347 | 0.6280 | Chinese Contact vs Pre-European |
| PC2 | 0.0655 | 0.7980 | Chinese Contact vs Post-European |

We also conducted size analysis by examining the body diameter of the vessels to explore any differences in vessel form reflected by size and shape. Body diameter is a suitable metric measurement to represent size for ceramics since it is associated with volume as a utilitarian function, and could present differences in the situation of similar shape. The body diameter of the vessels from Chinese period is larger than those from the two earlier periods, and the vessels before European contact have the smallest body diameter on average (Figure 6:A). It is interesting that linear regression model (Figure 6:B) predicts that shape, captured by PC1 and PC2, changes with size across three phases, except PC1 in Chinese period. That is, the shorter vessels are larger in body diameter according to the significant positive correlation between PC1 and size; however, the vessel from Chinese period does not show this pattern. On the contrary, the negative relationship between PC2 and size suggests that the vessels with narrower neck and mouth tend to have a larger body diameter.

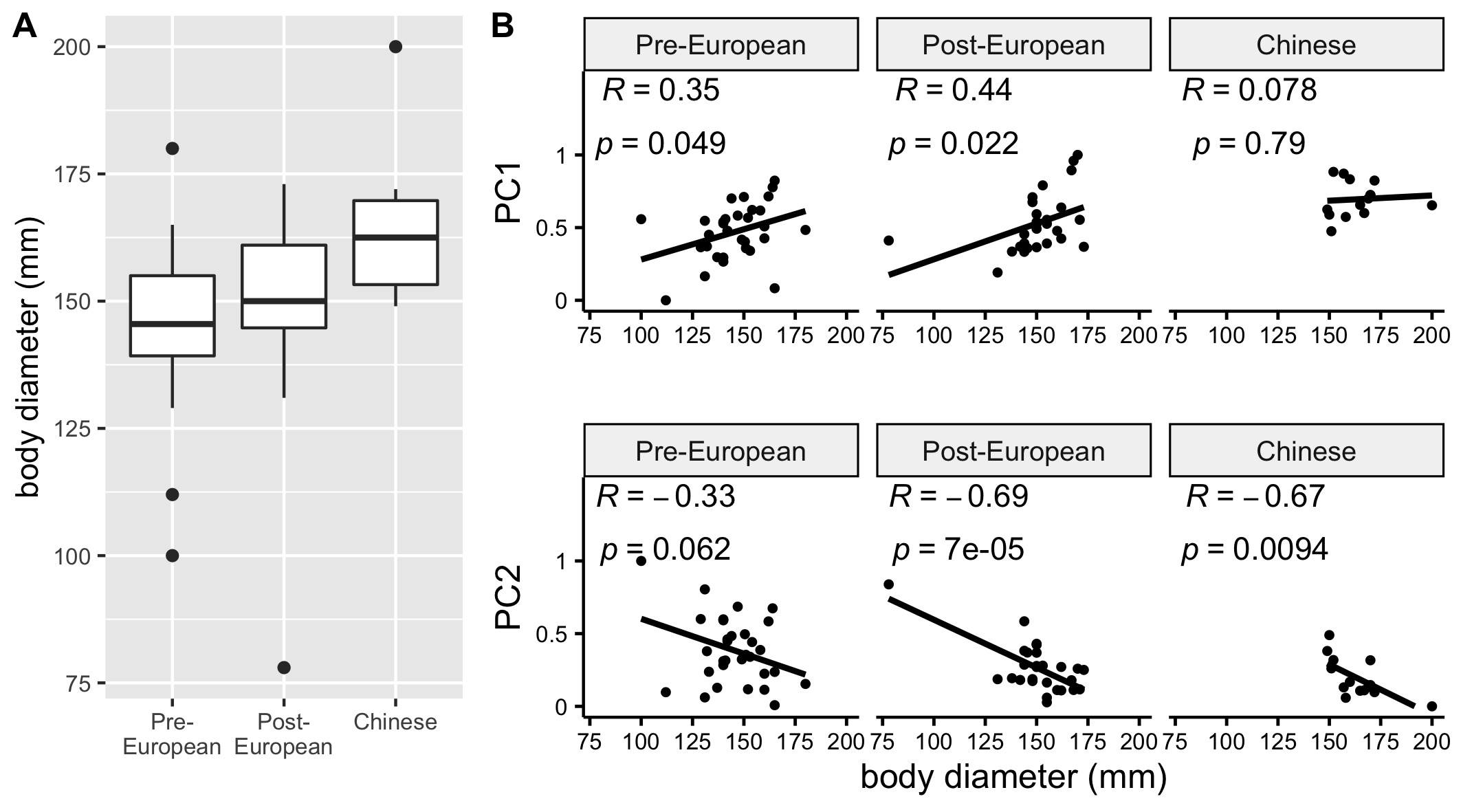


Figure 6: A: Distribution of the body diameter of the vessels across three phases. B: Scatter plots of shape variable, PC1 at the top and PC2 at the bottom, as a function of body diamater

# Discussion

Previous investigations at Kiwulan suggested an unequal distribution of prestige goods, trade ornaments in particular, following the appearance of Europeans (Cheng, 2008; Wang, 2011), which hinted at the emergence of social inequality within the Indigenous community. Ceramic vessel shape standardization was examined to measure craft specialization as a proxy for social differentiation (Costin, 2001; Junker, 1999). The result of our MANOVA demonstrates a significant difference in shapes between the pre-European and Post-European periods, and between the pre-European and the Chinese periods. The average shape presents as a round body with a wide rim and neck before European contact, which shifts to a more oval-shaped body with narrower rim and neck after the European presence. Shape changes are more pronounced during the Chinese contact period. In general, vessels become shorter in height over time, leading to an oval-shaped body. Moreover, size significantly varies with shape for vessels before and after the European presence, which presents that shorter vessels with narrower opening tend to have a larger body diameter. This correlation between size and shape can be also observed during the Chinese period without the consideration of height.

Our CV tests indicate that there are significant differences in shape standardization between the pre-European period and post-European period, and between the Chinese contact and either pre-European or post-European periods. Pottery shape became more homogeneous and standardized after contact with Europeans and even more so after contact with the Chinese. Compositional analysis shows that the clay pastes are similar, regardless of the increasing standardization of the pottery shape, reflecting continuity in the raw material sources. We can thus rule out changes in clay fabric as a factor in explaining changes in vessel shape. To determine if form changes might be related to changes in the function of pots at Kiwulan, we used geochemical methods to extract and identify lipids trapped in the fabric of potsherds to identify foods that may have contributed residues absorbed into the clay (cf. Kwak and Marwick, 2015). Unfortunately, we did not obtain useful results due to extremely low lipid yields, which is probably due to the very thin, dense, and low porosity fabric of Kiwulan pottery. These physical characteristics of the clay offer limited spaces to trap and protect organic molecules from microbiological degradation (cf. Evershed, 2008, p. 909).

The spatial analysis (Figure 7) for pottery samples presents multiple clusters with high densities of pottery during European presence. Hypothesis testing on spatial randomness indicates a non-randomly dispersed distribution before European contact and more extreme dispersed distribution after European presence. In contrast, the distribution of pottery is more similar to random distributions during the Chinese period. This contradicts our expectation that clustered pattern will be observed with an increase in pottery standardization since the emergence of specialized groups. The absence of clusters in the Chinese period is notable because this was a time of a historically-documented decline of Indigenous population (Chen, 2007; Hsieh, 2009). We might expect reduced numbers of potters to result in pottery production shrinking to a few locations in the settlement during this time. Although the overall number of vessels is smaller during the Chinese contact period, Figure 7 shows that pottery is distributed randomly across the sampling area without any distinctive clusters during this time. This suggests that differences in population across our three occupation phases are probably not driving variation in craft specialization.



Figure 7: A: The spatial distribution of the pottery selected for shape analysis. The quantity is indicated by the color scale. B: Kernel density map visulizes the probability of the density of pottery across space. The maps show a major core area during the pre-European period, multiple core areas during the European period, and a single core during the Chinese period. The bandwidth is based on Silverman (1986)

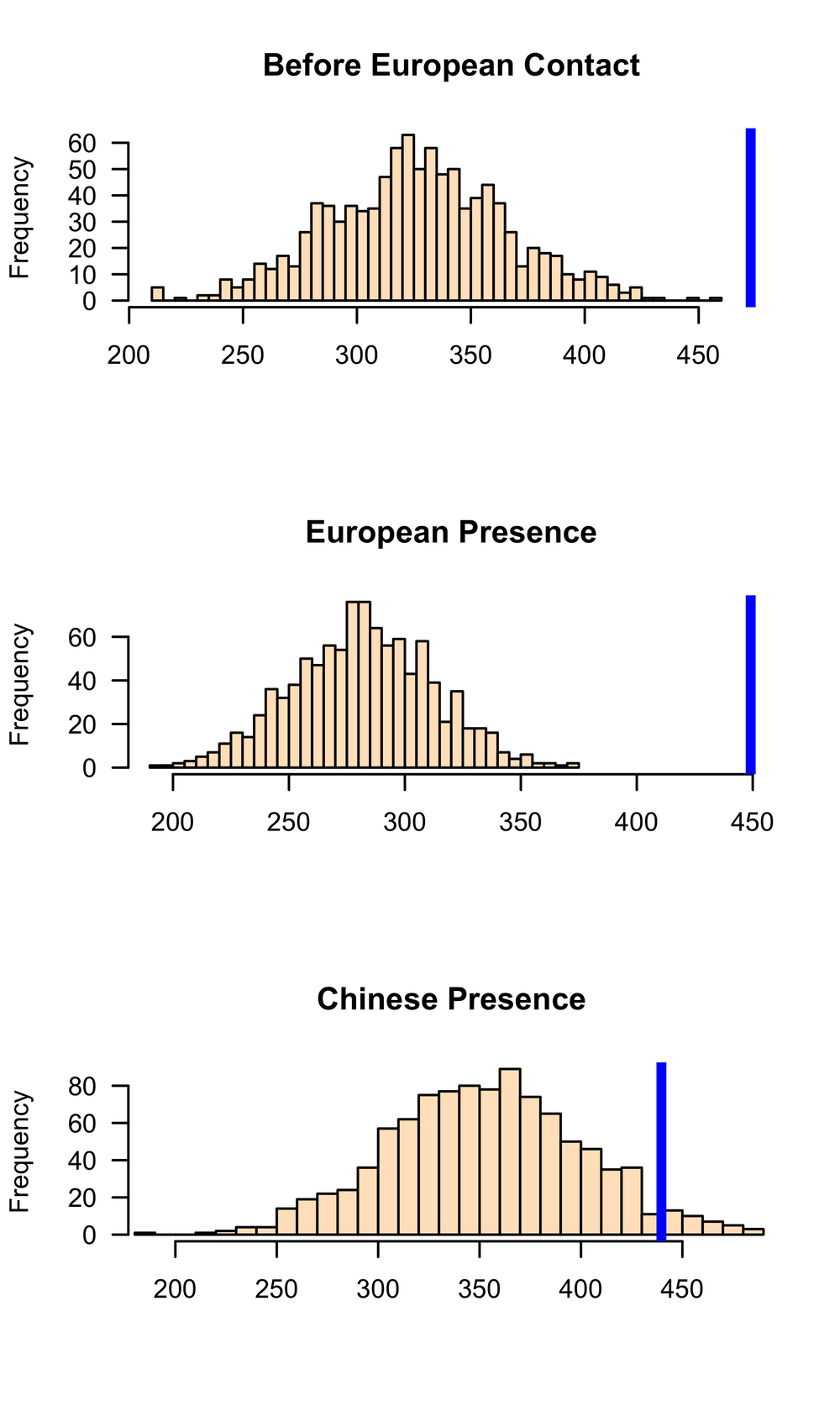


Figure 8: Histograms of simulated average nearest-neighbour distances (ANN) values from 1000 simulations for three phases. X-axis values based on meteres represent ANN expected value. Each sample distribution presents the null hypothesis with the blue line indicating the observed ANN value

Our results offer tentative support for the hypothesis that foreign influences at Kiwulan influenced emergence of social inequality in the local Indigenous society. If increased shape standardization is a reliable indicator of craft specialization, then we may be seeing evidence of a shift from corporate (group-based, distributed, collective, cooperative) to network (individual-based, competitive) organization (Blanton et al., 1996; Feinman, 2010, 2000, 1995; Feinman et al., 2000). However, strong claims for an emergence of social complexity resulting from foreign contact at Kiwulan will need support from multiple and diverse sources of evidence that are beyond the scope of this paper. We find that vessel shapes were more standardized during the Chinese period than the European period.

Compared to other regions in Taiwan, European colonial influence was weak in Yilan due to isolation by the surrounding mountains, and the economic focus of the Spanish and Dutch who preferred northern and northwest Taiwan as their trading base. Indigenous communities in Yilan experienced indirect influence from European trade networks and their colonial activities in a pericolonial context (cf. Acabado, 2017). In contrast to the Indigenous-European interactions at Kiwulan, the interaction between Indigenous people and Chinese immigrants in the 19th century appears to have been more intense and direct. Historical records indicate that Chinese groups settled in Yilan and lived closely with Kiwulan Indigenous societies (Chen, 1963; Ke, 1993). This direct influence is reflected by the archaeological evidence of large amounts of Chinese porcelains and distinctive architectural bricks and tiles used by Chinese (Hsieh, 2009). Similarly, burials at Kiwulan in this later phase show the adoption of coffins in mortuary practices, which Chiu (2004) interprets as the adoption of a symbol of ethnic Chinese.

The shape variation reported here is subtle, and invites consideration of the possibility that the absence of major changes in vessel shape at Kiwulan may have been an act of resistance to foreign influence. Continuities in vessel shape over time draws our attention to the endurance of traditional pottery production practices amid intrusions from Europeans and Chinese. In a culture contact situation, social identity may be expressed through material practices as a means of expressing cultural homogeneity and distinction from other groups (Voss, 2005). It is also important to recognize that social identity might be more complicated in a colonial context, and may be representative of more than a colonized–colonizer or local/foreign dichotomy (Voss, 2008, 2005). Shamaoshan cemetery dating from BC 3 to AD 4 in Southwest China suggests that the process of the incorporation of Southwest China into the Han Empire involved a century of conflicts, resistance, and acceptance among social groups with different identities, especially in the historical context of Han immigrants (Wu et al., 2019). A similar dynamic may have occurred at Kiwulan, with vessel shape indicating both acceptance of foreign influence through increased shape standardization, and resistance through the overall continuity in vessel shape. Vessel shape can be viewed as a symbolic expression the Indigenous identity and social boundaries because shape is a highly visible trait compared with other features of pottery (cf. Roux, 2015). Although there is an increase in number of imported ceramics through time at Kiwulan, production was continuous, and increasingly standardized. This might imply not only the utilitarian function, but a deliberate and increased emphasis on the local ceramic tradition, their cultural custom, as a response to intensified foreign contact (cf. Acabado, 2017).

# Conclusion

This study demonstrated an application of EFA on ceramic shapes to explore the emergence of ceramic specialization as indicative of foreign influences. Here, EFA is combined with a significance test for the equality of CVs of shape variables to provide a robust method of identifying and statistically assessing differences in shape standardization. The direct relationship between foreign influences and standardization of ceramic shape was tested on ceramics from Kiwulan, a large Iron Age Indigenous settlement in northeastern Taiwan. Lower variation in ceramic shape was identified after European presence began, and even lower variation during the period of Chinese presence. Our findings help to expand upon those factors that may lead to the standardization of ceramic production in a pericolonial interaction context. More homogeneous shapes during the contact periods, without any changes in clay paste composition or production technique, suggest that shape standardization was intentional. The results further suggest that expressions of social identity or cultural boundaries in Indigenous societies through highly visible vessel qualities, such as shape, may be heightened during periods of foreign contact in pericolonial contexts. Our analysis, with its openly available methods and data, is readily extensible to other pottery assemblages in the region to further explore related questions about craft specialization and standardization in Iron Age ceramic technologies.

# Acknowledgments

We would like to thank the Yilan County Cultural Affairs Bureau in Taiwan for permitting access to the pottery used in this study and providing the shape images. We thank Dr. Wen-Shan Chen in the Department of Geosciences, National Taiwan University for his invaluable guidance of petrographic analysis at his lab. We thank the Quaternary Research Center funding for supporting the organic residue analysis in this project. We thank Dr. Julian Sachs in the Department of Oceanography, University of Washington for his supports and providing his lab for us to conduct organic geochemistry analysis of potsherds. We thank Dr. Matthew Wolhowe for his help in developing protocols for lipid extraction and his assistance with the GC-MS, GC-FID, and GC-C-IRMS analyses. This research used statistical consulting resources provided by the Center for Statistics and the Social Sciences, University of Washington.

##### pagebreak

# References

Acabado, S., 2017. The archaeology of pericolonialism: Responses of the “unconquered” to spanish conquest and colonialism in ifugao, philippines. International Journal of Historical Archaeology 21, 1–26.

Adams, D.C., Rohlf, F.J., Slice, D.E., 2004. Geometric morphometrics: Ten years of progress following the “revolution”. Italian Journal of Zoology 71, 5–16.

Andrade, T., 2007. How Taiwan became chinese : Dutch, spanish, and han colonization in the seventeenth century. Columbia University Press, New York.

Archer, W., Gunz, P., Niekerk, K.L. van, Henshilwood, C.S., McPherron, S.P., 2015. Diachronic change within the still bay at blombos cave, south africa. PLoS One 10, e0132428.

Arnold, D.E., 2000. Does the standardization of ceramic pastes really mean specialization? Journal of Archaeological Method and Theory 7, 333–375.

Birch, T., Martinón-Torres, M., 2019. Shape as a measure of weapon standardisation: From metric to geometric morphometric analysis of the iron age ‘havor’lance from southern scandinavia. Journal of Archaeological Science 101, 34–51.

Blackman, M.J., Stein, G.J., Vandiver, P.B., 1993. The standardization hypothesis and ceramic mass production: Technological, compositional, and metric indices of craft specialization at tell leilan, Syria. American Antiquity 58, 60–80.

Blanton, R.E., Feinman, G.M., Kowalewski, S.A., Peregrine, P.N., 1996. A dual-processual theory for the evolution of mesoamerican civilization. Current anthropology 37, 1–14.

Boness, D., Clarke, J., Goren, Y., 2015. Ceramic neolithic pottery in cyprus—origin, technology and possible implications for social structure and identity. Levant 47, 233–254.

Bonhomme, V., Picq, S., Gaucherel, C., Claude, J., others, 2014. Momocs: Outline analysis using r. Journal of Statistical Software 56, 1–24.

Bookstein, F.L., 1997. Landmark methods for forms without landmarks: Morphometrics of group differences in outline shape. Medical image analysis 1, 225–243.

Buchanan, B., Andrews, B., O’Brien, M.J., Eren, M.I., 2018. An assessment of stone weapon tip standardization during the clovis–folsom transition in the western united states. American Antiquity 83, 721–734.

Buchanan, B., Collard, M., O’Brien, M.J., 2019. Geometric morphometric analyses support incorporating the goshen point type into plainview. American Antiquity 1–11.

Cardillo, M., 2010. Some applications of geometric morphometrics to archaeology, in: Elewa, A.M.T. (Ed.), Morphometrics for Nonmorphometricians. Springer, pp. 325–341.

Chen, S., 1963. Kavalan ting zhi [kavalen culture history], taiwan wen xian cong kan di 106 zhong [taiwan literature series: 106]. Economic Research Office, Bank ofTaiwan, Taipei.

Chen, W.-S., 2016. Tai wan di zhi gai lun [an introduction to the geology of taiwan]. Geological Society Located in Taipei.

Chen, Y.-p., 2007. Qi wu lan yi zhi qiang jiu fa jue bao gao [report on the archaeological excavations at ki-wu-lan site]. Lanyang museum, Yilan, Taiwan.

Cheng, C.-f., 2008. Qi wu lan yi zhi yu she nei yi zhi chu tu bo li zhu de xiang guan yan jiu [studies of glass beads excavated from kivulan and shenei site, Taiwan] (Master’s thesis).

Chiu, H.-l., 2004. Investigations of mortuary behaviors and cultural change of the kivulan site in i-lan county, Taiwan (Dissertation).

Claude, J., 2008. Morphometrics with r. Springer Science & Business Media.

Costin, C.L., 2001. Craft production systems, in: Archaeology at the Millennium. Springer, pp. 273–327.

Costin, C.L., 1991. Craft specialization: Issues in defining, documenting, and explaining the organization of production. Archaeological method and theory 1–56.

Dietler, M., 2015. Archaeologies of colonialism: Consumption, entanglement, and violence in ancient mediterranean france. Univ of California Press.

Dietler, M., 2005. The archaeology of colonization and the colonization of archaeology: Theoretical challenges from an ancient mediterranean colonial encounter, in: Stein, G. (Ed.), The Archaeology of Colonial Encounters: Comparative Perspectives. NM: Sch. Am. Res. Press, Santa Fe, pp. 33–68.

Dietler, M., 1997. The iron age in mediterranean france: Colonial encounters, entanglements, and transformations. Journal of World Prehistory 11, 269–358.

Doyon, L., 2019. On the shape of things: A geometric morphometrics approach to investigate aurignacian group membership. Journal of Archaeological Science 101, 99–114.

Eerkens, J.W., 2000. Practice makes within 5% of perfect: Visual perception, motor skills, and memory in artifact variation. Current Anthropology 41, 663–668.

Eerkens, J.W., Bettinger, R.L., 2001. Techniques for assessing standardization in artifact assemblages: Can we scale material variability? American Antiquity 66, 493–504.

Eren, M.I., Buchanan, B., O’Brien, M.J., 2015. Social learning and technological evolution during the clovis colonization of the new world. Journal of Human Evolution 80, 159–170.

Evershed, R.P., 2008. Organic residue analysis in archaeology: The archaeological biomarker revolution. Archaeometry 50, 895–924.

Feinman, G.M., 2010. A dual-processual perspective on the power and inequality in the contemporary united states: Framing political economy for the present and the past, in: Price, T.D., Feinman, G.M. (Eds.), Pathways to Power: New Perspectives on the Emergence of Social Inequality. Springer, pp. 255–275.

Feinman, G.M., 2000. Corporate/network: New perspectives on models of political action and the puebloan southwest. Social Theory in Archaeology, University of Utah Press, Salt Lake City 31–51.

Feinman, G.M., 1995. The emergence of inequality: A focus on strategies and processes, in: Price, T.D., Feinman, G.M. (Eds.), Foundations of Social Inequality. Springer Science & Business Media, New York: Plenum Press, pp. 255–275.

Feinman, G.M., Lightfoot, K.G., Upham, S., 2000. Political hierarchies and organizational strategies in the puebloan southwest. American Antiquity 65, 449–470.

Feltz, C.J., Miller, G.E., 1996. An asymptotic test for the equality of coefficients of variation from k populations. Statistics in medicine 15, 647–658.

Fox, A.N., 2015. A study of late woodland projectile point typology in new york using elliptical fourier outline analysis. Journal of Archaeological Science: Reports 4, 501–509.

Gero, J., Mazzullo, J., 1984. Analysis of artifact shape using fourier series in closed form. Journal of Field Archaeology 11, 315–322.

Given, M., 2004. The archaeology of the colonized. Routledge, London; New York.

Haruda, A., Varfolomeev, V., Goriachev, A., Yermolayeva, A., Outram, A., 2019. A new zooarchaeological application for geometric morphometric methods: Distinguishing ovis aries morphotypes to address connectivity and mobility of prehistoric central asian pastoralists. Journal of Archaeological Science 107, 50–57.

Hoggard, C.S., 2017. Considering the function of middle palaeolithic blade technologies through an examination of experimental blade edge angles. Journal of Archaeological Science: Reports 16, 233–239.

Hoggard, C.S., McNabb, J., Cole, J.N., 2019. The application of elliptic fourier analysis in understanding biface shape and symmetry through the british acheulean. Journal of Paleolithic Archaeology 2, 115–133.

Hsieh, E., 2009. Yi lan qi wu lan yi zhi chu tu wai lai tao ci qi zhi xiang guan yan jiu [the study of imported ceramics excavated at the ki-wu-lan site, i-lan] (Master’s thesis).

Ioviţă, R., 2009. Ontogenetic scaling and lithic systematics: Method and application. Journal of Archaeological Science 36, 1447–1457.

Ivanovaitė, L., Serwatka, K., Hoggard, C.S., Sauer, F., Riede, F., 2020. All these fantastic cultures? Research history and regionalization in the late palaeolithic tanged point cultures of eastern europe. European Journal of Archaeology 23, 162–185.

Junker, L.L., 1999. Raiding, trading, and feasting: The political economy of philippine chiefdoms. University of Hawaii Press.

Junker, L.L., 1993. Craft goods specialization and prestige goods exchange in philippine chiefdoms of the fifteenth and sixteenth centuries. Asian Perspectives 1–35.

Ke, P., 1993. Kavalan zhi lue [record of kavalen]. Historical Records Committee of Taiwan Provincial Government, Nantou.

Krishnamoorthy, K., Lee, M., 2014. Improved tests for the equality of normal coefficients of variation. Computational Statistics 29, 215–232.

Kuhl, F.P., Giardina, C.R., 1982. Elliptic fourier features of a closed contour. Computer graphics and image processing 18, 236–258.

Kuzminsky, S.C., Tung, T.A., Hubbe, M., Villaseñor-Marchal, A., 2016. The application of 3D geometric morphometrics and laser surface scanning to investigate the standardization of cranial vault modification in the andes. Journal of Archaeological Science: Reports 10, 507–513.

Kwak, S., Marwick, B., 2015. What did they cook? A preliminary investigation into culinary practices and pottery use in the central part of the korean peninsula during the mid to late holocene. Journal of Indo-Pacific Archaeology 37, 25–32.

Lawing, A.M., Polly, P.D., 2010. Geometric morphometrics: Recent applications to the study of evolution and development. Journal of Zoology 280, 1–7.

Lycett, S.J., Cramon-Taubadel, N. von, 2013. A 3D morphometric analysis of surface geometry in levallois cores: Patterns of stability and variability across regions and their implications. Journal of Archaeological Science 40, 1508–1517.

Lycett, S.J., Gowlett, J.A., 2008. On questions surrounding the acheulean “tradition”. World Archaeology 40, 295–315.

Marwick, B., 2017. Computational reproducibility in archaeological research: Basic principles and a case study of their implementation. Journal of Archaeological Method and Theory 24, 424–450. <https://doi.org/10.1007/s10816-015-9272-9>

Marwick, B., Boettiger, C., Mullen, L., 2018. Packaging data analytical work reproducibly using r (and friends). The American Statistician 72, 80–88.

Marwick, B., Krishnamoorthy, K., n.d. Cvequality: Tests for the equality of coefficients of variation from multiple groups.

Meloro, C., Hudson, A., Rook, L., 2015. Feeding habits of extant and fossil canids as determined by their skull geometry. Journal of Zoology 295, 178–188.

Mullins, P.R., 2011. The archaeology of consumption. Annual Review of Anthropology 40, 133–144.

Natahi, S., Coquerelle, M., Pereira, G., Bayle, P., 2019. Neurocranial shape variation among tarascan populations: Evidence for varying degrees in artificially modified crania in pre-hispanic west mexico (1200–1400 ad). American journal of physical anthropology 170, 418–432.

National Musuem of Taiwan History, A. group in, 2005. Taiwan under dutch and spanish: A report of historical archaeological research in northern taiwan. National Musuem of Taiwan History, Taipei.

Okumura, M., Araujo, A.G., 2014. Long-term cultural stability in hunter–gatherers: A case study using traditional and geometric morphometric analysis of lithic stemmed bifacial points from southern brazil. Journal of Archaeological Science 45, 59–71.

Perez, S.I., 2007. Artificial cranial deformation in south america: A geometric morphometrics approximation. Journal of Archaeological Science 34, 1649–1658.

R Core Team, 2019. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Rice, P.M., 1991. Specialization, standardization, and diversity: A retrospective, in: Bishop, R.L., Lange, F.W. (Eds.), The Ceramic Legacy of Anna O. Shepard. University Press of Colorado Boulder, pp. 257–279.

Roux, V., 2015. Standardization of ceramic assemblages: Transmission mechanisms and diffusion of morpho-functional traits across social boundaries. Journal of anthropological archaeology 40, 1–9.

Roux, V., 2003. Ceramic standardization and intensity of production: Quantifying degrees of specialization. American Antiquity 68, 768–782.

Saragusti, I., Karasik, A., Sharon, I., Smilansky, U., 2005. Quantitative analysis of shape attributes based on contours and section profiles in artifact analysis. Journal of Archaeological Science 32, 841–853.

Scaramelli, F., Scaramelli, K.T. de, 2005. The roles of material culture in the colonization of the orinoco, venezuela. Journal of Social Archaeology 5, 135–168.

Selden, R.Z., Dockall, J.E., Shafer, H.J., 2018. Lithic morphological organisation: Gahagan bifaces from the southern caddo area. Digital Applications in Archaeology and Cultural Heritage 10, e00080.

Selden Jr, R.Z., 2019. Ceramic morphological organisation in the southern caddo area: The clarence h. Webb collections. Journal of Cultural Heritage 35, 41–55.

Selden Jr, R.Z., 2018. Ceramic morphological organisation in the southern caddo area: Quiddity of shape for hickory engraved bottles. Journal of Archaeological Science: Reports 21, 884–896.

Selden Jr, R.Z., Dockall, J.E., Dubied, M., 2020. A quantitative assessment of intraspecific morphological variation in gahagan bifaces from the southern caddo area and central texas. Southeastern Archaeology 39, 125–145.

Silliman, S., 2001. Agency, practical politics and the archaeology of culture contact. Journal of social archaeology 1, 190–209.

Silliman, S.W., 2005. Culture contact or colonialism? Challenges in the archaeology of native North America. American Antiquity 55–74.

Slice, D.E., 2007. Geometric morphometrics. Annu. Rev. Anthropol. 36, 261–281.

Smith, H.L., DeWitt, T.J., 2016. The northern fluted point complex: Technological and morphological evidence of adaptation and risk in the late pleistocene-early holocene arctic. Archaeological and Anthropological Sciences 9, 1799–1823.

Stark, B.L., 1995. Problems in analysis of standardization and specialization in pottery, in: Mills, B.J., Crown, P.L. (Eds.), Ceramic Production in the American Southwest. The University of Arizona Press, Tucson, pp. 231–267.

Tite, M.S., 1999. Pottery production, distribution, and consumption—the contribution of the physical sciences. Journal of archaeological method and theory 6, 181–233.

Topi, J.R., VanPool, C.S., Waller, K.D., VanPool, T.L., 2017. The economy of specialized ceramic craft production in the casas grandes region. Latin American Antiquity 29, 122–142.

Torrence, R., Clarke, A., 2000. Negotiating difference: Practice makes theory for contemporary archaeology in Oceania, in: Torrence, R., Clarke, A. (Eds.), The Archaeology of Difference : Negotiating Cross-Cultural Engagements in Oceania. Routledge, London; New York, pp. 1–31.

Trabert, S., 2017. Considering the indirect effects of colonialism: Example from a great plains middle ground. Journal of Anthropological Archaeology 48, 17–27.

Voss, B.L., 2008. Between the household and the world system: Social collectivity and community agency in overseas chinese archaeology. Historical Archaeology 37–52.

Voss, B.L., 2005. From casta to californio: Social identity and the archaeology of culture contact. American Anthropologist 107, 461–474.

Wang, L.-Y., 2011. Yi lan qi wu lan yi zhi chu tu zhuang shi pin zhi xiang guan yan jiu [a research of ornaments excavated at ki-wu-lan site, i-lan] (Master’s thesis).

Wilczek, J., Monna, F., Barral, P., Burlet, L., Chateau, C., Navarro, N., 2014. Morphometrics of second iron age ceramics–strengths, weaknesses, and comparison with traditional typology. Journal of archaeological science 50, 39–50.

Wills, M.A., 2001. Morphological disparity: A primer, in: Fossils, Phylogeny, and Form. Springer, pp. 55–144.

Wu, X., Hein, A., Zhang, X., Jin, Z., Wei, D., Huang, F., Yin, X., 2019. Resettlement strategies and han imperial expansion into southwest china: A multimethod approach to colonialism and migration. Archaeological and Anthropological Sciences 11, 6751–6781.

##### pagebreak

### Colophon

This report was generated on 2020-07-24 10:24:24 using the following computational environment and dependencies:

#> ─ Session info ───────────────────────────────────────────────────────────────  
#> setting value   
#> version R version 4.0.2 (2020-06-22)  
#> os macOS Catalina 10.15.6   
#> system x86\_64, darwin17.0   
#> ui X11   
#> language (EN)   
#> collate en\_US.UTF-8   
#> ctype en\_US.UTF-8   
#> tz America/Los\_Angeles   
#> date 2020-07-24   
#>   
#> ─ Packages ───────────────────────────────────────────────────────────────────  
#> package \* version date lib source   
#> abind 1.4-5 2016-07-21 [1] CRAN (R 4.0.0)   
#> ape 5.4 2020-06-03 [1] CRAN (R 4.0.0)   
#> assertthat 0.2.1 2019-03-21 [1] CRAN (R 4.0.0)   
#> backports 1.1.8 2020-06-17 [1] CRAN (R 4.0.0)   
#> blob 1.2.1 2020-01-20 [1] CRAN (R 4.0.0)   
#> bookdown 0.20 2020-06-23 [1] CRAN (R 4.0.0)   
#> broom 0.7.0 2020-07-09 [1] CRAN (R 4.0.2)   
#> callr 3.4.3 2020-03-28 [1] CRAN (R 4.0.0)   
#> car 3.0-8 2020-05-21 [1] CRAN (R 4.0.0)   
#> carData 3.0-4 2020-05-22 [1] CRAN (R 4.0.0)   
#> cellranger 1.1.0 2016-07-27 [1] CRAN (R 4.0.0)   
#> class 7.3-17 2020-04-26 [1] CRAN (R 4.0.2)   
#> classInt 0.4-3 2020-04-07 [1] CRAN (R 4.0.0)   
#> cli 2.0.2 2020-02-28 [1] CRAN (R 4.0.0)   
#> colorspace 1.4-1 2019-03-18 [1] CRAN (R 4.0.0)   
#> cowplot \* 1.0.0 2019-07-11 [1] CRAN (R 4.0.0)   
#> crayon 1.3.4 2017-09-16 [1] CRAN (R 4.0.0)   
#> crosstalk 1.1.0.1 2020-03-13 [1] CRAN (R 4.0.0)   
#> curl 4.3 2019-12-02 [1] CRAN (R 4.0.0)   
#> cvequality \* 0.2.0 2019-01-07 [1] CRAN (R 4.0.0)   
#> data.table 1.12.8 2019-12-09 [1] CRAN (R 4.0.0)   
#> DBI 1.1.0 2019-12-15 [1] CRAN (R 4.0.0)   
#> dbplyr 1.4.4 2020-05-27 [1] CRAN (R 4.0.0)   
#> desc 1.2.0 2018-05-01 [1] CRAN (R 4.0.0)   
#> devtools 2.3.0 2020-04-10 [1] CRAN (R 4.0.0)   
#> digest 0.6.25 2020-02-23 [1] CRAN (R 4.0.0)   
#> dplyr \* 1.0.0 2020-05-29 [1] CRAN (R 4.0.0)   
#> e1071 1.7-3 2019-11-26 [1] CRAN (R 4.0.0)   
#> ellipsis 0.3.1 2020-05-15 [1] CRAN (R 4.0.0)   
#> evaluate 0.14 2019-05-28 [1] CRAN (R 4.0.0)   
#> fansi 0.4.1 2020-01-08 [1] CRAN (R 4.0.0)   
#> farver 2.0.3 2020-01-16 [1] CRAN (R 4.0.0)   
#> fastmap 1.0.1 2019-10-08 [1] CRAN (R 4.0.0)   
#> forcats \* 0.5.0 2020-03-01 [1] CRAN (R 4.0.0)   
#> foreign 0.8-80 2020-05-24 [1] CRAN (R 4.0.2)   
#> fs 1.4.2 2020-06-30 [1] CRAN (R 4.0.0)   
#> generics 0.0.2 2018-11-29 [1] CRAN (R 4.0.0)   
#> geomorph \* 3.3.1 2020-07-23 [1] Github (geomorphR/geomorph@248e1cd)  
#> ggforce 0.3.2 2020-06-23 [1] CRAN (R 4.0.0)   
#> ggplot2 \* 3.3.2 2020-06-19 [1] CRAN (R 4.0.0)   
#> ggpubr \* 0.4.0 2020-06-27 [1] CRAN (R 4.0.2)   
#> ggsignif 0.6.0 2019-08-08 [1] CRAN (R 4.0.0)   
#> glue 1.4.1 2020-05-13 [1] CRAN (R 4.0.0)   
#> gridExtra 2.3 2017-09-09 [1] CRAN (R 4.0.0)   
#> gtable 0.3.0 2019-03-25 [1] CRAN (R 4.0.0)   
#> haven 2.3.1 2020-06-01 [1] CRAN (R 4.0.0)   
#> here \* 0.1 2017-05-28 [1] CRAN (R 4.0.0)   
#> highr 0.8 2019-03-20 [1] CRAN (R 4.0.0)   
#> hms 0.5.3 2020-01-08 [1] CRAN (R 4.0.0)   
#> htmltools 0.5.0 2020-06-16 [1] CRAN (R 4.0.0)   
#> htmlwidgets 1.5.1 2019-10-08 [1] CRAN (R 4.0.0)   
#> httpuv 1.5.4 2020-06-06 [1] CRAN (R 4.0.0)   
#> httr 1.4.1 2019-08-05 [1] CRAN (R 4.0.0)   
#> jpeg 0.1-8.1 2019-10-24 [1] CRAN (R 4.0.0)   
#> jsonlite 1.7.0 2020-06-25 [1] CRAN (R 4.0.0)   
#> KernSmooth 2.23-17 2020-04-26 [1] CRAN (R 4.0.2)   
#> knitr 1.29 2020-06-23 [1] CRAN (R 4.0.0)   
#> labeling 0.3 2014-08-23 [1] CRAN (R 4.0.0)   
#> later 1.1.0.1 2020-06-05 [1] CRAN (R 4.0.0)   
#> lattice 0.20-41 2020-04-02 [1] CRAN (R 4.0.2)   
#> lifecycle 0.2.0 2020-03-06 [1] CRAN (R 4.0.0)   
#> lubridate 1.7.9 2020-06-08 [1] CRAN (R 4.0.0)   
#> magick \* 2.4.0 2020-06-23 [1] CRAN (R 4.0.0)   
#> magrittr 1.5 2014-11-22 [1] CRAN (R 4.0.0)   
#> manipulateWidget 0.10.1 2020-02-24 [1] CRAN (R 4.0.0)   
#> MASS 7.3-51.6 2020-04-26 [1] CRAN (R 4.0.2)   
#> Matrix 1.2-18 2019-11-27 [1] CRAN (R 4.0.2)   
#> memoise 1.1.0 2017-04-21 [1] CRAN (R 4.0.0)   
#> mgcv 1.8-31 2019-11-09 [1] CRAN (R 4.0.2)   
#> mime 0.9 2020-02-04 [1] CRAN (R 4.0.0)   
#> miniUI 0.1.1.1 2018-05-18 [1] CRAN (R 4.0.0)   
#> modelr 0.1.8 2020-05-19 [1] CRAN (R 4.0.0)   
#> Momocs \* 1.3.0 2020-04-15 [1] CRAN (R 4.0.0)   
#> munsell 0.5.0 2018-06-12 [1] CRAN (R 4.0.0)   
#> nlme 3.1-148 2020-05-24 [1] CRAN (R 4.0.2)   
#> openxlsx 4.1.5 2020-05-06 [1] CRAN (R 4.0.0)   
#> pillar 1.4.4 2020-05-05 [1] CRAN (R 4.0.0)   
#> pkgbuild 1.0.8 2020-05-07 [1] CRAN (R 4.0.0)   
#> pkgconfig 2.0.3 2019-09-22 [1] CRAN (R 4.0.0)   
#> pkgload 1.1.0 2020-05-29 [1] CRAN (R 4.0.0)   
#> png 0.1-7 2013-12-03 [1] CRAN (R 4.0.0)   
#> polyclip 1.10-0 2019-03-14 [1] CRAN (R 4.0.0)   
#> prettyunits 1.1.1 2020-01-24 [1] CRAN (R 4.0.0)   
#> processx 3.4.3 2020-07-05 [1] CRAN (R 4.0.0)   
#> promises 1.1.1 2020-06-09 [1] CRAN (R 4.0.0)   
#> ps 1.3.3 2020-05-08 [1] CRAN (R 4.0.0)   
#> purrr \* 0.3.4 2020-04-17 [1] CRAN (R 4.0.0)   
#> R6 2.4.1 2019-11-12 [1] CRAN (R 4.0.0)   
#> RColorBrewer 1.1-2 2014-12-07 [1] CRAN (R 4.0.0)   
#> Rcpp 1.0.5 2020-07-06 [1] CRAN (R 4.0.0)   
#> readr \* 1.3.1 2018-12-21 [1] CRAN (R 4.0.0)   
#> readxl 1.3.1 2019-03-13 [1] CRAN (R 4.0.0)   
#> remotes 2.1.1 2020-02-15 [1] CRAN (R 4.0.0)   
#> reprex 0.3.0 2019-05-16 [1] CRAN (R 4.0.0)   
#> rgl \* 0.100.54 2020-04-14 [1] CRAN (R 4.0.0)   
#> rio 0.5.16 2018-11-26 [1] CRAN (R 4.0.0)   
#> rlang 0.4.7 2020-07-09 [1] CRAN (R 4.0.2)   
#> rmarkdown 2.3 2020-06-18 [1] CRAN (R 4.0.0)   
#> rprojroot 1.3-2 2018-01-03 [1] CRAN (R 4.0.0)   
#> RRPP \* 0.6.1 2020-06-24 [1] CRAN (R 4.0.0)   
#> rrtools 0.1.0 2020-06-24 [1] Github (benmarwick/rrtools@f43aae1)  
#> rstatix 0.6.0 2020-06-18 [1] CRAN (R 4.0.0)   
#> rstudioapi 0.11 2020-02-07 [1] CRAN (R 4.0.0)   
#> rvest 0.3.5 2019-11-08 [1] CRAN (R 4.0.0)   
#> scales 1.1.1 2020-05-11 [1] CRAN (R 4.0.0)   
#> sessioninfo 1.1.1 2018-11-05 [1] CRAN (R 4.0.0)   
#> sf \* 0.9-4 2020-06-13 [1] CRAN (R 4.0.0)   
#> shiny 1.5.0 2020-06-23 [1] CRAN (R 4.0.0)   
#> stringi 1.4.6 2020-02-17 [1] CRAN (R 4.0.0)   
#> stringr \* 1.4.0 2019-02-10 [1] CRAN (R 4.0.0)   
#> testthat 2.3.2 2020-03-02 [1] CRAN (R 4.0.0)   
#> tibble \* 3.0.2 2020-07-07 [1] CRAN (R 4.0.0)   
#> tidyr \* 1.1.0 2020-05-20 [1] CRAN (R 4.0.0)   
#> tidyselect 1.1.0 2020-05-11 [1] CRAN (R 4.0.0)   
#> tidyverse \* 1.3.0 2019-11-21 [1] CRAN (R 4.0.2)   
#> tweenr 1.0.1 2018-12-14 [1] CRAN (R 4.0.0)   
#> units 0.6-7 2020-06-13 [1] CRAN (R 4.0.0)   
#> usethis 1.6.1 2020-04-29 [1] CRAN (R 4.0.0)   
#> vctrs 0.3.1 2020-06-05 [1] CRAN (R 4.0.0)   
#> viridis \* 0.5.1 2018-03-29 [1] CRAN (R 4.0.0)   
#> viridisLite \* 0.3.0 2018-02-01 [1] CRAN (R 4.0.0)   
#> webshot 0.5.2 2019-11-22 [1] CRAN (R 4.0.0)   
#> withr 2.2.0 2020-04-20 [1] CRAN (R 4.0.0)   
#> xfun 0.15 2020-06-21 [1] CRAN (R 4.0.0)   
#> xml2 1.3.2 2020-04-23 [1] CRAN (R 4.0.0)   
#> xtable 1.8-4 2019-04-21 [1] CRAN (R 4.0.0)   
#> yaml 2.2.1 2020-02-01 [1] CRAN (R 4.0.0)   
#> zip 2.0.4 2019-09-01 [1] CRAN (R 4.0.0)   
#>   
#> [1] /Library/Frameworks/R.framework/Versions/4.0/Resources/library

The current Git commit details are:

#> Local: master /Users/EmilyWang/Desktop/School document/LW-Paper/kwl-pottery-2019  
#> Remote: master @ origin (https://github.com/LiYingWang/kwl.pottery.git)  
#> Head: [8c33103] 2020-07-24: update description file

Word count: 5074