Micro-Regional Complexities in Yayoi Pottery Form as Seen through Morphometric Statistical Analysis

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ABSTRACT

Microregional studies on ceramic form have continued to elucidate detailed notions of differential production practices for several decades. With the wide proliferation of accessible morphometric analysis, statistically reproducible morphometric analysis of shape has quickly become an international standard in this field of archaeological practice. However, with few studies on Yayoi period pottery utilizing reproducible statistical analysis at a micro-regional level; morphological micro-styles, which may elucidate differential learning practices, have been systematically overlooked. In response to this oversight, this study seeks to elucidate the full range of potential micro-regional morphological variance through the utilization of complex morphometric analysis. Results in the Northern Kyushu region show that previous research which primarily utilizes typo-chronological methodology at a macro-spatial scale has failed to account for the full range of complexities of pottery variation during this period. Through the use of multivariate statistical analysis of shape, two morphological micro-styles within the 65 km Northern Kyushu micro-region have become clear. These two micro-styles, through the inclusion of ethnoarchaeological studies, may elude to differential learning methods as well as divergent degrees of morphological standardization over time.

KEYWORDS: Ceramics, Multivariate Statistical Analysis, Yayoi Period, Morphometrics, Pottery Production

1. Introduction

1.1 Pottery as a socio-cultural time capsule

Across the many decades since the formalization of archaeology as a sub-discipline of anthropology, the analysis of pottery has consistently proven to be an extremely reliable medium to reconstruct prehistoric production systems (Gandon *et al.* 2020). Due to the pliability of clay, continuous "checking" of vessel form during the production process allows for intentional replication of socio-culturally determined model forms. In this way, pottery acts as a societal time capsule, freezing a very small sliver of the societal context it was created in, and in doing so, a keen archaeologist can extrapolate the traces and patterns of this sliver of time (Orton & Hughes 2013; Roux 2019). By doing so, recreation of spatial as well as temporal changes of the given production, and in turn, societal context

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is possible. As these traces left on the vessels can range from the overall form of the pot to minute changes in motor skills of the individual potters, holistic analysis is required to locate and interpret these traces. Often times, the changes in these traces over time are so minute that even over hundreds of years it may be difficult to grasp any change at all, and incorporation of other aspects of the larger societal complex from other material culture goods may be necessary to create a cohesive flow of change, and by doing so, the methods and organization of production can be inferred (Santacreu 2014).

1.2 The Initial/Early Yayoi period

In large-scale societal transitional contexts such as the Initial/Early Yayoi period, these changes are much more prominent, with material culture quickly transforming over a relatively short period (archaeologically speaking); with several waves of demic migration from the Korean Peninsula into the Northern Kyushu region due to various periods of climatic cooling (Miyamoto 2014, 2015, 2016), not only was large-scale wet rice cultivation technology introduced to the indigenous Jomon populations, but also changes in the style, form, and production process of pottery. Thus, the Jomon-Yayoi transitional period serves as a suitable case study in the search of minute changes in vessel form that may elude to complexities in the acceptance and rejection of different technologies, and has for many years been a staple in Japanese archaeology as a point of great interest as well as contention (Mizoguchi 2013).

However, few studies seeking to clarify changes in vessel form have utilized reproducible statistical analysis, and as such, cannot be independently verified via scientific means. Within the chosen region of study of Northern Kyushu in particular, major studies on pottery production often fall within several major themes such as migration patterns from the continent, differential production methods between the Jomon and "Yayoi" populations, or tracing pottery lineages. While such studies are extremely useful in understanding general notions of socio-cultural contexts and macro-scale changes in production methods through differential migration and settlement patterns; in terms of elucidating micro-regional variance of pottery form, the methodology used in many of these studies fails to be statistically reproducible, instead relying on subjective intuitive experience through the primary use of typo-chronological analysis, of which is based on the categorization of vessel form into idiosyncratic "attributes." For this reason, not only has the scholarship failed to move past rehashing of typo-chronologies, Yayoi period research has yet to be fully accepted into an international stage, of which such basic reproducibility is a standard practice in modern studies. This is not to say that studies utilizing statistical analysis have yet to be conducted at all. Previous scholars such as Nakazono (2004) have utilized similar traditional morphometric based distance-measurements in the extrapolation of variable types in the Northern Kyushu region, with special focus paid on the Ogori region and local adoption of new production practices. However, as to be discussed further in the methods section of this study, a lack of statistical significance testing via a robust multivariate statistical means such as MANOVA (multivariate analysis of variance) calls into question the statistical validity of certain claims of variable continuity, especially over a long temporal period. As Nakazono's work has laid the foundation for further studies utilizing this practice within this region and period, this work is a main point of methodological contention to be overcome through future robust methods.

This study, a part of a larger PhD research project, seeks to build upon previous scholar's works while also expanding methodological frameworks in order to overcome the continuous issues of scientific reproducibility in Japanese archaeological practice. This project seeks to move beyond cultural-historical typo-chronologies in order to statistically quantify the overlooked degree of small-scale variation in the archaeological record during the Jomon-Yayoi transitional period. This is done through a micro-regional case study of the northern Kyushu region, known widely as the first point of contact between the indigenous Jomon and incoming migrant populations (Yane 1984). Pottery is used as the main item of study due to its additive properties as compared to other material items introduced during the same period (stone goods, glass, wooden agricultural tools, etc.) as well as the exciting potential for continuity of pottery production skills between the Jomon and Yayoi. Morphometric analysis through the utilization of multivariate statistics is used as the primary method of ceramic morphological analysis.

2. Materials and methods

2.1 Periodization

The beginnings of what is now known as the "Yayoi period" is still a point of strong contention among many contemporary scholars, and what constitutes the beginnings of the Yayoi culture is a continuously evolving line of research. Scholars have at several key points throughout the progression of Yayoi period studies have pointed to different factors or objects which should be considered the beginning of the Yayoi culture, such as Yuusu type pottery (Sahara 1975; Okazaki 1971), and the AMS dates provided by the National Museum of Japanese History in 2003. This paper tentatively accepts the results given by Miyamoto (2016) of typological cross-dating and the earliest example of irrigated wet rice agriculture from the 8th century BC as a decent marker for the beginnings of the Yayoi period for the sake of this current project, although this is not a point of argument in this current project.

2.2 Region

The Northern Kyushu area, specifically the Karatsu, Itoshima, Fukuoka, and Munakata sub-regions were chosen as the main areas of analysis, as they are known to be the initial areas of interaction between indigenous Jomon and the incoming migrant cultures (Sahara 1975, 1981; Sugihara 1961; Yane 1984) (Figure 1, Table 1).

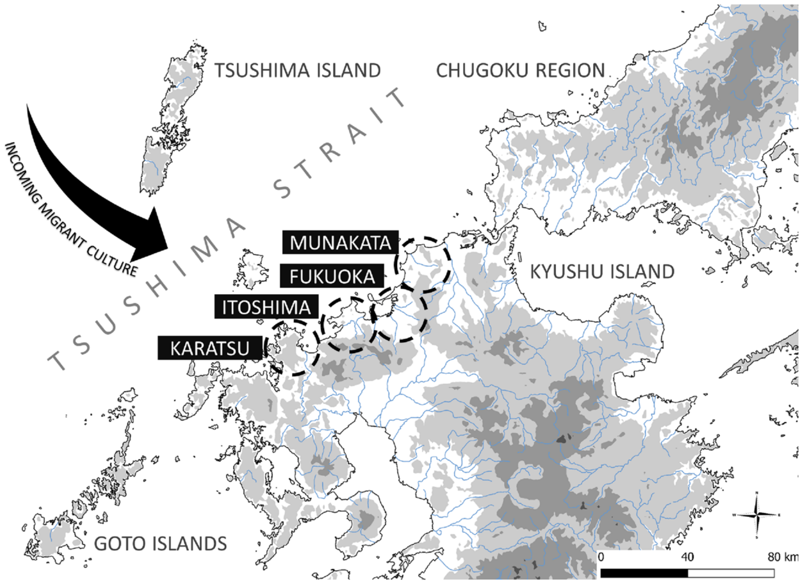

Figure 1. The Northern Kyushu region and associated subregions of Munakata, Fukuoka, Itoshima and Karatsu

Table 1. Initial-Early Yayoi period sites within the Northern Kyushu region utilized in this study

MUNAKATA	FUKUOKA	ITOSHIMA	KARATSU
Togonoboritate 東郷登リ立	Sasai 雀居	Shinmachi 新町	Nabatake 菜畑
Imagawa 今川	Itazuke 板付	Ishizaki-Magarita 石崎曲り田	
	Shimotsukiguma-Tenjinmori 下月隈・天神森		
	Goryomaenoen 御陵前ノ椽		
	Naka Terao 中・寺尾		

2.3 Materials

2.3.1 Tsubo globular pot

Due to the complexities in production methods depending on differential shape-types and usage of vessels during the initial-early Yayoi period, the globular "tsubo" pots (壺型土器) (henceforth referred to as tsubo) are chosen as the main item of study. These small pots (average height of 15～20 cm) were first introduced into the northern Kyushu region directly from the Korean peninsula, without any similar shape type being seen during the previous Jomon period.

The shapes of these vessels can range anywhere from long-neck, angular bodied vessels to that of a shorter neck with a distinctly globular body shape (Figure 2). These differences in general shape have the potential of possessing a high micro-regional spatial difference. Fired at a relatively low temperature, these course-ware vessels range from rough to polished with black lacquer and red pigments. Despite originating from the Korean (無文, mumon) pottery tradition, over half of the excavated examples in northern Kyushu have incised patterns on the upper half of the body section, starting from the widest point of the body to the connecting point between the upper body and neck. However, several outlying vessels in the Itoshima plain region show patterns on the lower body and neck of vessels as well. Incised patterns range from horizontal straight lines to more intricate 'wave' and herringbone style patterns (Figure 3), with the body of the pot smoothed and incised using a variety of tools such as shells, wooden sticks, etc. (Imamura 2011).

These pots were primarily deposited in mortuary contexts, either surrounding or found within the various styles of burials prominent during the initial/early Yayoi period in Northern Kyushu (Misaka 2014). These burial styles ranged from simple rectangular

Figure 2. An example of an early Yayoi "tsubo" globular pot. Shimotsukiguma C site, Fukuoka

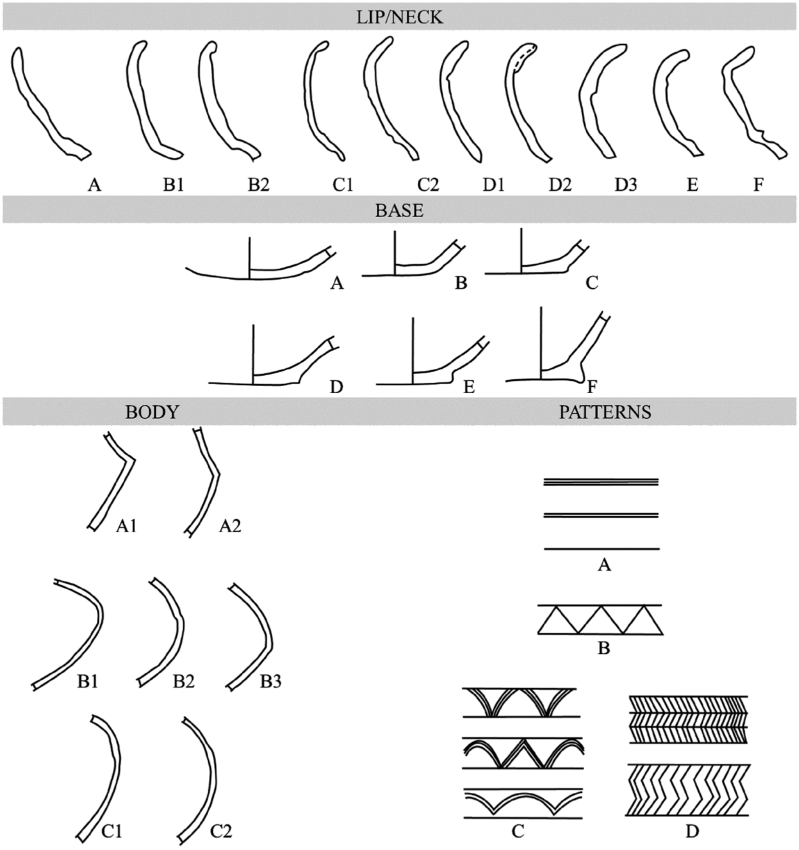

Figure 3. Main pottery attributes (Lip/neck, Base, Body, and Patterns) associated with northern Kyushu "tsubo" pots

pit burials similar to those during the late Jomon period, to stone-lined, wooden-coffin, dolmen, and jar style burials. Diversity lays not only in the style of burials themselves, but also in the spatial layout of burial complexes. Ranging from hilltop burials with possibilities of social strata, long rows of various burial styles lined along a preexisting road, to seemingly haphazard burials which overlap each other, but may elude to clues of the beginnings of a change from social-orientated burials to those that "manifest a genealogical connection and a continuity between the dead" through "sequential burial clusters" (Mizoguchi 2014).

The micro-regional complexities of tsubo pots act as an extremely useful case study due to the intended usage and deposition context of the pots being primarily mortuary in nature. As compared to cooking jars "kame," pedestaled dishes "takatsuki," etc., the tsubo's relative dating can be extrapolated not only utilizing the stylistic changes of the pots themselves, but also that of the burial styles in which they were recovered. Certain burial styles such as the jar burial only became prominent in the Northern Kyushu region during the latter part of the early Yayoi period, while dolmen burials introduced during the latter part of the initial Yayoi period saw a very strictly confined temporal and spatial limit within the micro-region itself. Due to these contextual changes in burial styles, not only can the tsubo pots be more accurately placed in a sequential temporal order, pots with strong correlations to certain mortuary practices can be spatially traced over the several hundred-year transitional period. The tsubo's place as typically the only surviving burial good to be found in initial/early Yayoi burials gives the vessels a very distinct place as compared to the middle Yayoi, where a much larger plethora of burial goods such as stone swords, glass beads, iron goods, etc. can be found. Several other scholars have also appreciated the usefulness of the tsubo in extrapolating various notions of socio-cultural diversity and production methods during this period (Hashino 2016, 2018; Nakazono 2004).

A total of 220 samples from various sites across the Northern Kyushu region have been compiled for use in both typo-chronology building as well as the extrapolation of micro-regional variance through the use of geometric morphometric analysis (Table 2). 111 partial samples or sherds containing at least 2 of the main morphological attributes outlined

Table 2. Tsubo samples utilized in this study

Area	Site	Sherd/Partial Vessel	Whole Vessel	TOTAL
Munakata	Togonoboritate	2	5	7
Munakata	Imagawa	4	9	13
Fukuoka	Sasai	9	16	25
Fukuoka	Itazuke	26	12	38
Fukuoka	Tenjinmori	4	11	15
Fukuoka	Goryomaenoen	0	9	9
Fukuoka	Nakaterao	3	15	18
Itoshima	Shinmachi	11	20	31
Itoshima	Magarita	33	2	35
Karatsu	Nabatake	19	10	29
TOTAL		111	**109**	220

109 whole vessel samples were utilized in the following geometric morphometric analysis, with 111 sherds/partial vessels incorporated in the building of typo-chronological stages.

in Figure 3 are included in typology building due to the relatively small number of full vessels available in the earliest stages of the study period. The remaining 109 full vessel samples are tested using a variety of geometric morphometric statistical analysis to gauge relative degrees of differential changes in form across time-space.

2.3.2 Chronology building

While working within a scholarship that has yet to adopt AMS dating in a holistic way; in order to maintain the general structure of temporality when completing not only this analysis, but all following statistical analysis, the use of chronological seriation is paramount (Figure 4). All vessels have been placed within a relative time-phase within the 9-phase chronological seriation, however one glaring problem regarding the size of the sample still persists. Some phases, especially those earlier phases, have much fewer vessels that complete morphometric data could be extrapolated from. Thus, when calculating these vessels into not only cluster, but also principal component analysis, the actual nature of the shape type of those very detailed time-phases may be misrepresented in the final data analysis. Thus, it was understood that instead of the strict utilization of the 9-phase chronological seriation itself, it was necessary to understand any larger changes across these time phases in terms of large-scale time-stages. This was done by further categorization of vessels into a 3-stage temporal system based on periods of largest morphological change in vessel form.

The notion that there were various

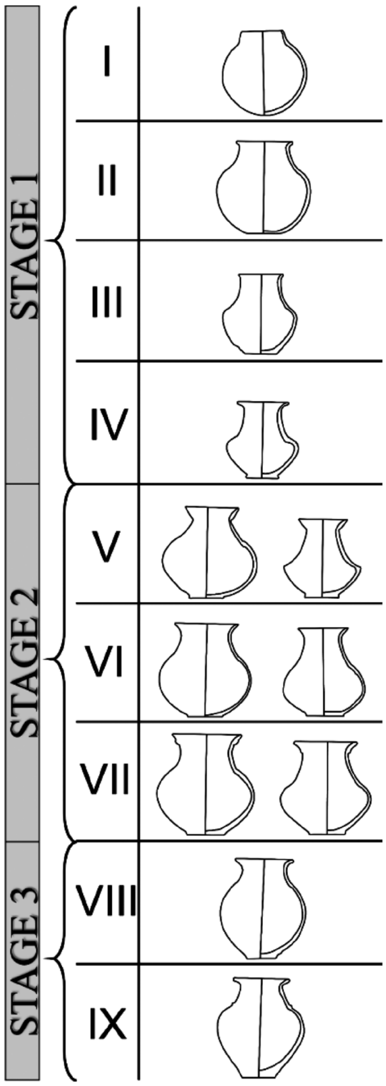

Figure 4. Tsubo pot (Northern Kyushu) chronological framework

periods of large-scale changes in the style and shape-types of vessels during this period is not a new idea, and has been touched on before, and especially by Miyamoto (2019), who argues that large scale changes not only in pottery production, but also the culture as a whole in the Northern Kyushu region took place during the Itazuke 1 phase of the traditional chronological-seriation. Through geometric morphometric means, the presence or absence of morphological changes in vessel form due to such socio-cultural shifts may be discernable.

2.4 Methodology

2.4.1 Geometric Morphometrics

Geometric morphometrics (henceforth referred to as GMM) is a wide range of potential elucidations of shape through statistical means. While Cooke & Terhune (2015) define GMM as “a collection of approaches for the multivariate statistical analysis and visualization or Cartesian coordinate data,” it may be more beneficial in this example to visualize GMM as a group of differential statistical analysis, of which certain beneficial analysis are chosen to use in tandem for the main purpose of extrapolating variance in the form of the sample at hand. Despite the wide net that GMM casts, the study of general morphometrics consists of multiple methods of data extrapolation and proceeding statistical analysis applied to said data. Each of the 3 main methods of data extrapolation (Traditional, Landmark, Outline) have strengths and weaknesses that will fit better with the nature of the samples being used.

2.4.2 Traditional Morphometrics

Traditional morphometrics, as defined by Webster & Sheets, “summarizes morphology in terms of length measurements, ratios, or angles, that can be investigated individually or several at a time” (Webster & Sheets 2010). Distance extrapolation involves measuring the distance between certain important morphological points, and is most often utilized in biological samples, however has also been used in morphologically similar material cultural samples as well in order to extrapolate the degree of production standardization (Nakazono 2004; Wang & Marwick

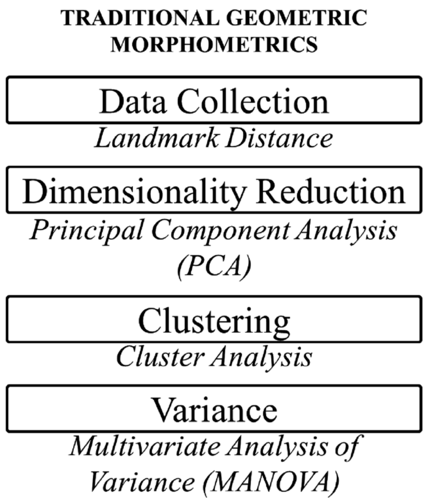

Figure 5. Traditional morphometric analysis utilized in this study

2020).

Often times, traditional methods may fail to sufficiently extract clear morphological variance between differential shape type and/or across extremely morphologically varied material cultural goods due to a majority of variance falling within what can be considered differential size factors (such as widest width or height). However, within goods of relatively low intra-group morphological variance, especially with regards to size factors, it is possible to extrapolate important morphological notions of variance over space and time. The chosen traditional morphometric analysis in this study are outlined in Figure 5, with a general workflow summarized in Section 2.4.3.

Landmark distances are categorized into 3 categories; 1. Height variables, 2. Width variables, and 3. Thickness variables (Figure 6). Largely based on previous studies of northern Kyushu Yayoi pottery these points represent the distances between and within the key points of interest in terms of changes in the overall morphological shape of the vessel (Nakazono 2004). This is in contrast with Shennan's (1988) use of taking measurements at even intervals from the top to the bottom of the vessel. This interpretation often clumps different points of interest together, and does not help to reduce the observable and unobservable changes in vessel form, but instead over generalize variation and limits the degree of morphological elucidation that can be processed from the vessel form.

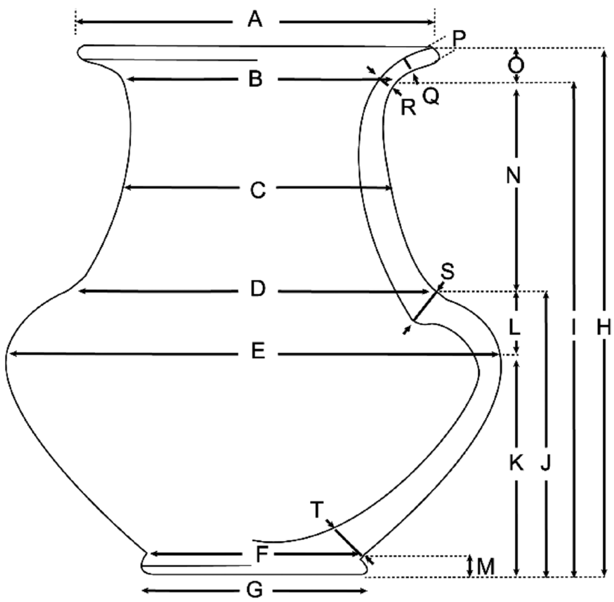

Figure 6. 20 landmark distances utilized in this study (A–T)

Due to the nature of this process of taking a very strict set of landmarks across vessels, the number of usable samples was severely reduced to about half of the original sample size, from a total of ~200 samples to that of 109 vessels. However, the distribution of these vessels across sites still can be seen as representative of the actual micro-regional pottery production processes at the time, with vessels almost equally represented evenly across all original sites.

2.4.3 Analysis Workflow

The chosen traditional morphometric toolkit of analysis used in this study to extrapolate temporal and spatial factors of shape transformations are briefly summarized below by each desired outcome, with a general summary of the analysis workflow conducted to follow (1. Image extraction, 2. Landmark distance extraction, 3. General morphological distribution, 4. Ordination/data reduction, 5. Morphological clustering, 6. Inter-variable & inter-group significance testing).

1. Image extraction

Archaeological excavation reports are scanned at a minimum of 600 DPI, and outlying data is removed with the original scaling of the image kept intact. Each individual image file of each vessel is then cleaned up and manually outlined in image editing software such as GIMP or Photoshop.

2. Landmark distance extraction

Landmark distance measurements are taken from the 2d outlines provided in relevant site reports using a combination of Adobe Photoshop, ImageJ (Schneider *et al.* 2012) and Adobe Illustrator. As the original scales are intact from the image extraction process, a simple standard measurement of 30 cm is set within ImageJ, and measurements between morphological "landmarks" are extracted utilizing the "measure" function. Following the successful extraction of 20 distance measurements for each of the given samples, the list of measurement data is exported to an excel file for statistical analysis.

3. General morphological distribution

General morphological distribution through the utilization of distance measurements is extracted through the use of general box-plot analysis of the aforementioned 20 morphological distances. Measurements are extracted from the exported excel sheet and box-plot analysis is conducted in PAST via the "plot→boxplot" function (Hammer *et al.* 2001).

4. Ordination/data reduction

Principal Component Analysis (PCA)

Due to the high degree of dimensionality in distance data, it is necessary to reduce this dimensionality to the most important degrees of variance. PCA is most commonly used in the ordination and reduction of dimensionality in this regard. PCA is a dimensionality reduction method that "reduces dimensionality by performing a singular value decomposition of the variance-covariance matrix and extracting the resulting eigenvectors, which then form the principal components" (Cooke & Terhune 2015). These principal components in turn come to represent the highest notions of morphological variance, provided that each PC represents relatively different areas of a craft good's form. PCA is conducted via the PAST function "Multivariate→Ordination→Principal Components (PCA)." Only the first two components accounting for the highest degree of morphological variance are retained for plotting purposes.

5 Morphological clustering

Cluster Analysis (based on Mahalanobis distance index)

Although PCA is often mistaken as a method of morphological clustering, and while PCA can give ideas as to the number of potential clusters and the general distribution of vessels within a morphospace, specific clustering methods are necessary to clarify these notions. General cluster analysis based on Mahalanobis distance is utilized to this end in this study. Cluster analysis is utilized across almost all studies seeking to "group" samples, whether this be through traditional, landmark or outlined-based GMM. This study utilizes the Mahalanobis similarity index due to the following two shortcomings of the Euclidean index: 1. Euclidean indexes are overly sensitive to changes in the scales of the variables involved. Traditionally this problem arises from the utilization of variables with vastly different scales (e.g. height, weight, age, etc.). While this study may not overtly have such drastic differences, the differences between say height and extremely fine thickness points seem to be overly weighted in this analysis, skewing the results. 2. Euclidean indexes do not account for correlated variables. This point is extremely important in the analysis of this study's data set, in that almost all of the variables are highly co-correlated. Also, many variables have almost identical values (especially in the case of thickness points), thus the use of a Euclidean index overly weights the second, third, fourth and so on variables that have similar values, extremely skewing results.

6. Inter-variable & inter-group significance testing

Multivariate Analysis of Variance (MANOVA)

While conducting morphometric analysis may yield interesting morphological results, not all data sets or chosen grouping methods may yield statistically significant results,

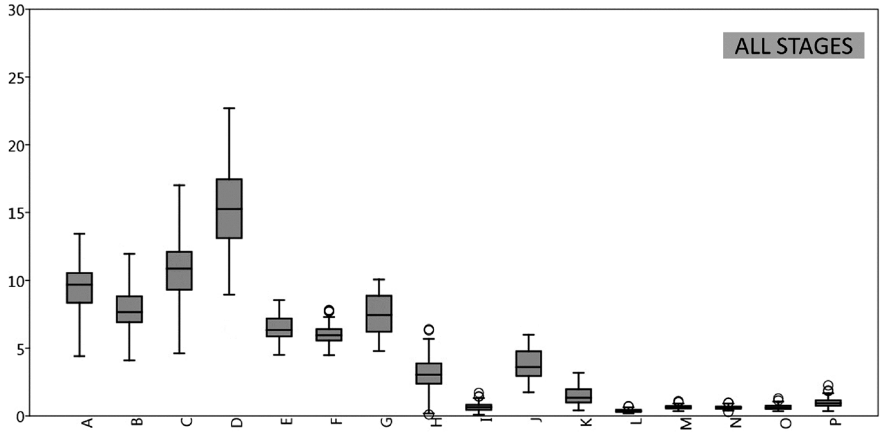

Figure 7. Box plot analysis (all stages)

and as analysis such as PCA or cluster analysis do not test for significance, it is necessary to the test robustness of each chosen grouping through a separate means. MANOVA is a statistical method which tests relative statistical significance between multiple variables across multiple samples (Bray & Maxwell 1985). In this example, MANOVA is conducted via PAST, under the "Multivariate→Tests→MANOVA" function in order to extrapolate which variables show a statistically significant change in form between the three temporal stages.

3. Results

Based on a three-stage temporal analysis of pottery styles situated within the typo-chronological sequence explained above, results show that previous research which primarily utilizes typo-chronological methodology at a macro-spatial scale has failed to account for the full range of complexities of pottery variation during this period. Through the use of multivariate statistical analysis within the 3-stage temporal period, it has been shown that there existed at least 2 micro-styles within the 65-kilometer micro-region. Results are categorized based on the aforementioned categorical workflow process (1. General morphological distribution, 2. Ordination/data reduction, 3. Morphological clustering, 4. Inter-variable & inter-group significance testing).

3.1 General morphological distribution

Box plot analysis on all distance measurements shows that variables with the highest degree of variation from the mean are mostly related to upper body and neck/lip attributes, while those with lower degrees of variation from the mean are those related to the lower

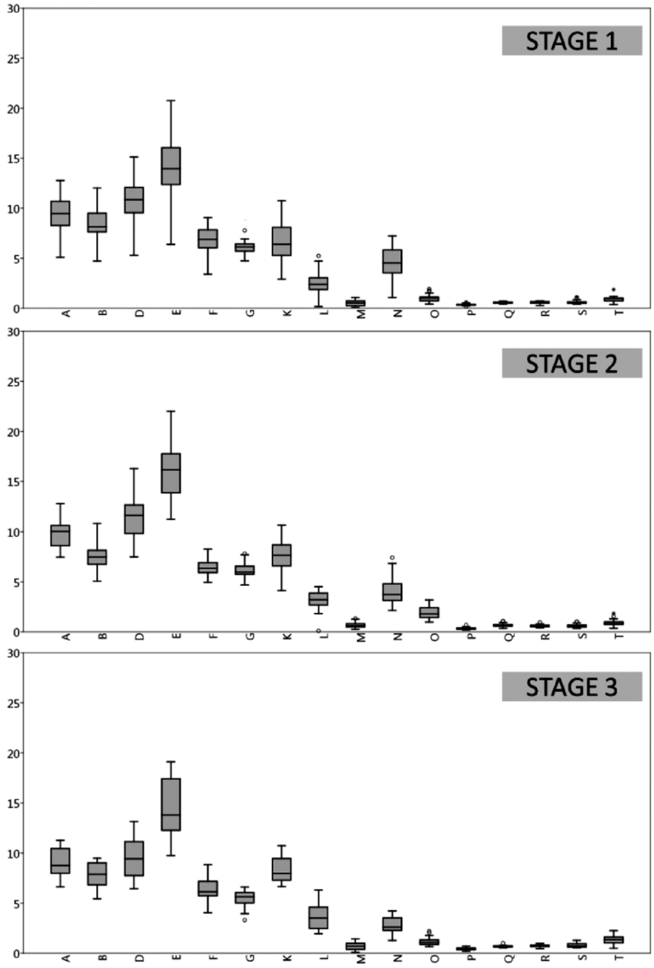

Figure 8. Box plot analysis (individual stages)

body and base attributes (Figure 7). Thus, in terms of overall variation present in each of the landmark distance variables as well as the vessel attributes, it can be understood that vessels can be divided into two main morphological sections based on differential degrees of variance.

With regards to each stage analysed seperately, an interesting temporal pattern arises from differential degrees of variation between variables (Figure 8). Overall analysis in the variation from mean values across all 3 stylistic stages showed that significant changes in overall variation was present. While there are statistically significant differences in the degree of variation between upper and lower vessels points, as a whole all points (with lower vessel points being the highest) experienced a lessening of variation from the mean

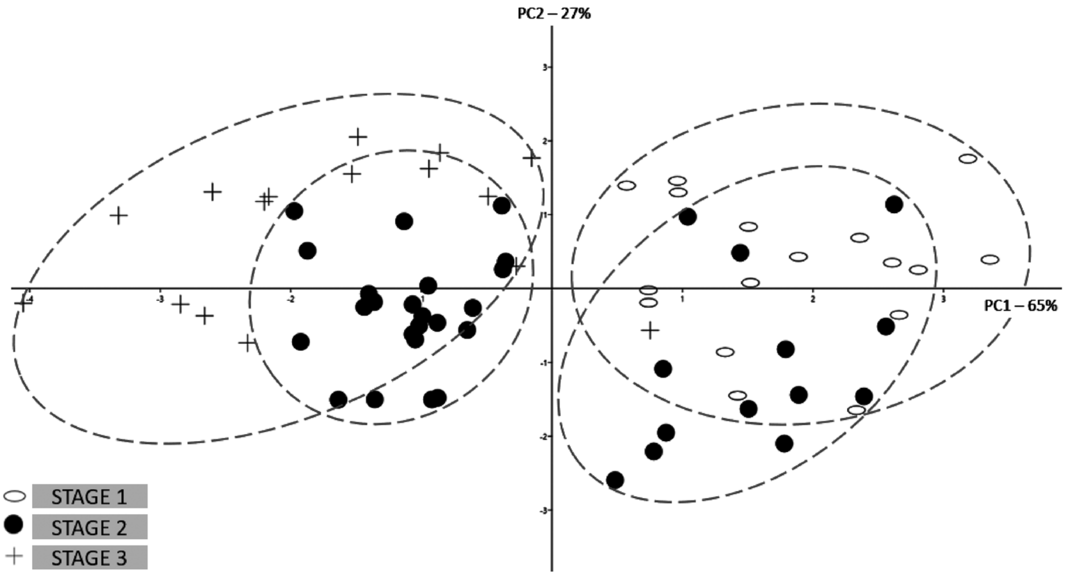

Figure 9. Principal Component Analysis (3 stage system) PC1: 65% (B, C, D, H, and N), PC2: 27% (G, J, K)

over time. Through this analysis it can be understood that there existed at a regional level, possible notions of morphological standardization of vessel style/shape over time. With special attention paid to stage 3 vessels, it can be understood that especially within the upper-vessel variables, variance reduced intensely as compared to the previous stages.

3.2 Ordination/data reduction

Principal component analysis was conducted utilizing the previously outlined landmark distances (Figure 9), and per normal practice only components with eigenvalues over 1 were included in the potential comparison. Principal component 1 (PC1) accounted for approximately 65% of total variance, with highest coefficient correlations being with regard to points B, C, D, H, and N, all values (except H) being associated with the upper half of the pot (from the upper lip to the upper half of the body). Principal component 2 (PC2) accounted for approximately 27% of total variance, with highest coefficient correlations being with regard to points G, J, and K, or the lower half vessels. While not all variables are equally represented, general differential morphological patterns from both the upper and lower portions of vessels could be understood. These results align with the previously mentioned differential degrees of variance between upper and lower vessel variables. Figure 9, an overall PCA analysis of vessels from all 3 stages shows several interesting results outlined below:

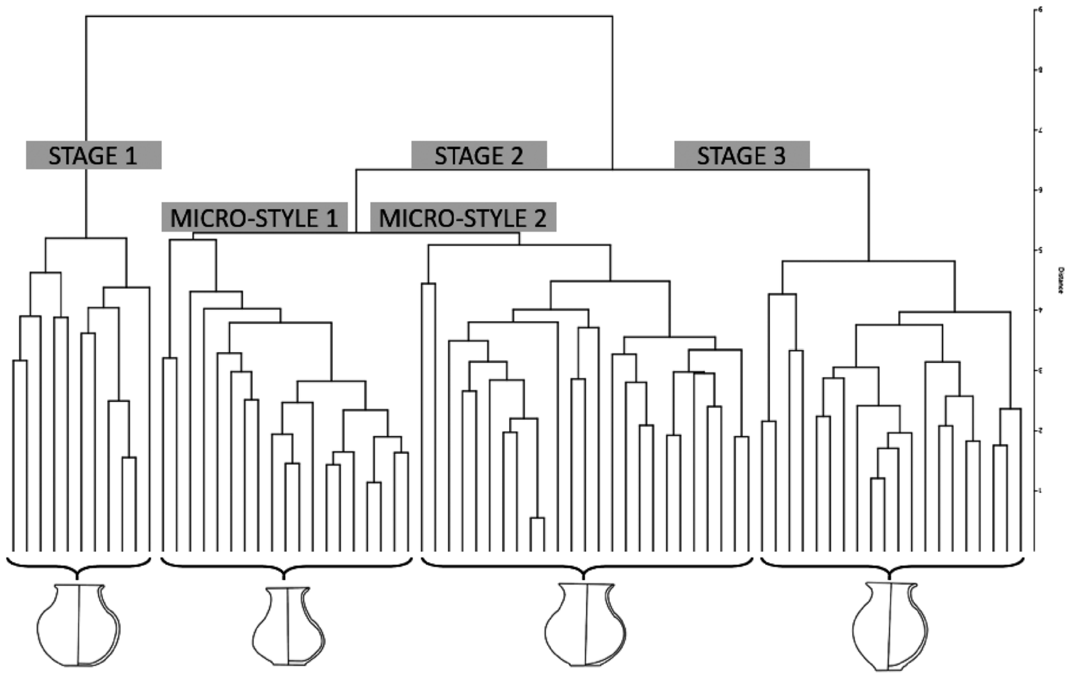

Figure 10. Cluster analysis (all vessels) (overlaid average cluster shapes for clarity)

1. Stage 2 vessels are split into 2 smaller groups, correlating more closely to either stage 1 or stage 3 points accordingly.
2. The overlap between each of the stage 2 micro groups overlaps heavily with stage 1 and stage 3 vessels, this slightly mirrors results seen in the previously mentioned cluster analysis.

3.3 Morphological clustering

Cluster analysis was completed using the neighbor-joining clustering method Mahalanobis similarity index in PAST (Figure 10). The corresponding average shapes of each morphological cluster and the majority stage is also overlaid for clarity.

Overall it can be noted that aside from stage 2 vessels, most vessels of the same time-stage tend to cluster closely with one another, and do not vary much in terms of not only their distance from one another up and down but also from left and right, with only a few examples of outliers within a mini-cluster. Clusters are spread into 3 main groups situated on the same level of axis, with various mini-clusters making these up. As previously mentioned, temporality is divided into 3 main time-stages. Stage 1 vessels seem to have a large degree of overall variation, with vessels spread across the majority of the

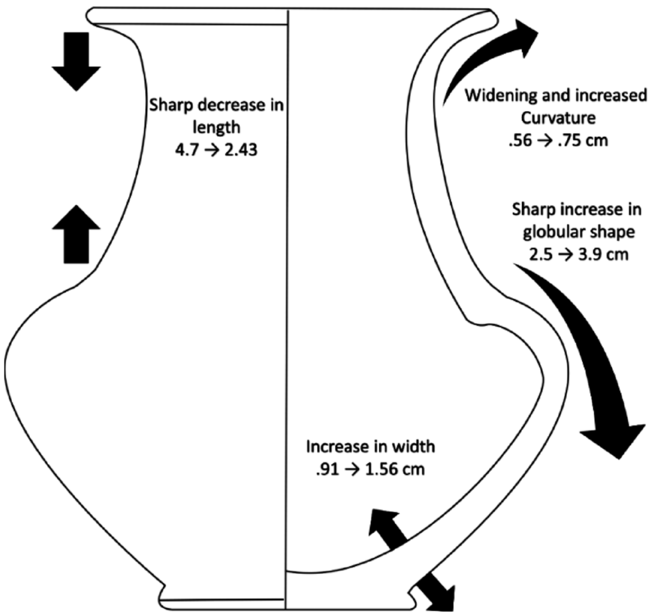

Figure 11. Multivariate Analysis of Variance (MANOVA) results from statistically significant changes (p<.05, stages 1–3)

morphological landscape. Stage 2 vessels are split into two main clusters centering at slowly below the upper portion of the spectrum, and at the lower quadrant of the analysis. Stage 3 vessels are more tightly correlated; most being dispersed in the right quadrant of the cluster analysis.

3.4 Inter-variable & inter-group significance testing

In order to uphold the temporal integrity of the samples, MANOVA was performed between vessels of each of the 3 stages in order to understand at a holistic level whether or not the overall changes in form would be statistically significant, and if they would mirror the previously understood results of a gradual change from stage 2 angular and globular vessels to primarily globular vessels with small necks in the third stage (Figure 11). Overall, with a significance level of p value $<.05$, the overall statistically significant changes to vessel form from stage 1 to stage 3 are outlined as follows:

1. An increase in the width and curvature of the lip of pots
2. The body shape widens and has a more globular curvature
3. The neck length shortens drastically
4. The connecting point between the base and the body widens

3.5 Summary

Combining the breadth of each individual analysis into a synthesized argument, morphometric results show two significant morphological characteristics of pottery form during the initial-early transitional period, 1. Differential intra-vessel variance, 2. Micro-regional micro-styles. Firstly, both between general box plot analysis as well as PCA, the upper portion of vessels tend to hold the highest degree of morphological variance as compared to the lower portion of vessels. Secondly, through cluster analysis, PCA and MANOVA, it can be understood that during stage 2, there existed two morphologically separable groups of vessels that tend to cluster more closely to the previous stage 1 vessels, or that of stage 3 vessels respectively. These two micro-styles, while generally similar in morphology, show very minute differences in the length of the lip/neck region as well as the degree of roundness of the globular body of vessels.

4. Discussion

Results from traditional morphometric analysis have elucidated several differential styles of vessel form within the Northern Kyushu region during the initial/early Yayoi period. With a closer look at the micro-scale, 2 statistically distinct micro-styles during stage 2 (coinciding with the introduction of the Itazuke type) emerged, and through the incorporation of ethnographic studies on material cultural production contexts, with special attention paid to the process of ceramic standardization; it may be deduced that pottery producing communities within this small micro-region during earlier periods incorporated a varying degree of stylistic choice when creating vessel form, but this variable style was either erased or incorporated into a standardized production practice by the end of the early Yayoi period.

4.1 Pottery Standardization

Results showing a decrease in overall variable variance between and within vessels temporally have potentials of elucidating general changes in pottery production, and in turn, learning contexts during this period. In traditional studies of production standardization, changes in the degrees of relative standardization within a material cultural good may be interpreted as a reactionary clue to the makeup of production groups, or the degree of specialization held by agents (Costin 1991). While in prehistoric contexts, often times the only existing, testable notion of production contexts is that of the material good itself ("indirect evidence"; Costin 1991); differential variance in form/shape is often a reliable indicator of changes in these production contexts (Arnold & Nieves 1992). As such, with the inclusion of a framework of production standardization and its connection to differential learning methods, a sliver of the variety of potential production methods during this period is possible to reconstruct.

Costin (1991, 2000) and Arnold (2000) note that standardization of material cultural production is broken down into 3 stages; First, the intensification of production. Second, the specialization of pottery production by a select few or group of individuals within the group context. Third, reduces the degree of variation within the style and shapes of vessels. Due to the nature of archaeological materials, this process must be studied in reverse, with the variation of vessels being the main object of study, and the first two stages being inferred from the data, solidified with ethnographic examples.

Rice (1981) notes that the standardization of vessel style and shape can only be reasonably understood through "a small group of individuals utilizing a limited range of materials and somewhat formalized or routinized techniques that result in virtually identical procedures such as mass production," as opposed to the entire group of individuals in a cultural system utilizing the same techniques, as these individuals all carry varying degrees of their own personal styles and backgrounds (Rice 1981). With the assumption that the lowering of overall vessel variation was due to the specialization of pottery production by a smaller group of individuals comes with it two assumptions:

1) Large-scale, intense production of pottery can only be feasibly performed by a specialized group of full-time potters due to the relative amount of time necessary to produce vessels at a high-rate being outside the technical skill of non-skilled potters. Which leads to the second assumption that:
2) Small-scale production can be performed by either full-time potters, or more likely, a larger group of part-time potters (Roux 2003). As Roux (2003) notes, groups with large-scale, intense production of pottery *do* show a significantly lower degree of variation among all points. In this way, as shown through the 3 stages, it can be assumed that not only was pottery production specialized, but was done so through the production of pottery by a smaller group of full-time potters.

Synthesizing the aforementioned results of the tsubo globular pot, the above standardization framework, and socio-cultural background context; it becomes clear that key factors in material cultural standardization took place during the initial/early Yayoi period in the Northern Kyushu region. Firstly, as previously mentioned, increases in population, especially with regards to population density, may play a key role in the narrowing of potential variance in form through the increase of production intensity. During the early Yayoi period, due to several waves of migration from the Korean peninsula, the site density within the Northern Kyushu region, especially within plains regions, increased dramatically (Miyamoto 2016). Furthermore, population estimations during this period also show marked increases in population density around the mid-stage 2 period (Kim & Park 2020; Watanabe *et al.* 2019), overlapping with a general increase in pottery intensification, especially within micro-style 2 vessels. Secondly, the degree of variance within the intensified micro-style 2 vessels and stage 3 vessels, of which seem to be morphologically close to micro-style 2 vessels, sharply falls during this period. These results also align with Miyamoto's model of migration patterns and the spread of "Yayoi culture" throughout western Japan, necessitating a relatively standardized form of material culture during the period which aligns with stage 2 in this study (Miyamoto 2014, 2016).

These results show that despite an increase in site and population density during the initial/early Yayoi period, a decrease in the variety of vessel form must be indicative of a conscious and widespread change in the production context of pottery, to that of small-group style, specialized potters (Roux 2003). As the need for the mortuary pottery of the tsubo globular pot increased during stage 2, a lower number of specialized potters was a necessary change in order to successfully increase the production intensity to a sufficient level (Blackman *et al.* 1993).

4.2 Learning processes

It has been noted that the attachment of a social dimension to the humanoid actions of individuals and groups is due to the process of the transmission of information regarding pottery production techniques through the act of learning (Baldi & Roux 2016). Utilizing Reed and Bril's (1996) notion of "tutor, learner and models," it is possible to discern to a large degree the learning process of pottery production during this period, at least with regards to the mortuary pottery of the tsubo globular pot. It has already been noted that there existed a standardization of pottery production among a relatively small group of specialists. It is then fair to reason that these specialists were taught the process of pottery

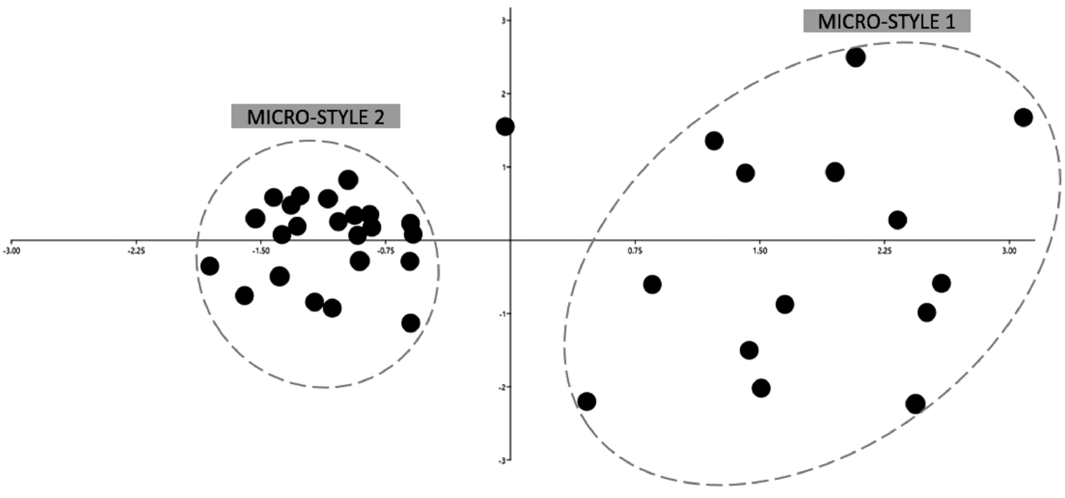

Figure 12. PCA output for stage 2 vessels, highlighting the two micro-styles

production from other, more experienced potters, utilizing a process of observation of a model vessel, and replication of this model. This notion can be understood through the use of statistical analysis to recognize the existence of clustering around a model shape-type. Results from PCA shed light on this phenomenon, albeit only to a certain extent due to small sample sizes.

Focusing specifically on clustering in stage 2 (Figure 12), where patterns are most clearly visible, three general conclusions may be deduced:

1) The existence of 2 micro-styles is evidence of two different systems of learning, and differences in the series of stylistic technological choice over time was at play in order to create such a stylistic difference.
2) Tight clustering around a “model” style in the micro-style type 2 is evidence of a system of “tutor, learner, and model” learning as outlined by Reed and Bril (1996). This model style is not bound to one site, but the process of learning is dispersed across multiple sites in the central Fukuoka plain region.
3) The existence of an area-wide system of “tutor, learner, and model” learning in the central Fukuoka plain region as seen in micro-style type 2 can be indicative of an establishing system of pottery standardization by a smaller group of specialized individuals within each site.

From these conclusions, it is possible to deduce that within micro-style 2 vessels there existed a system of a methodically rigorous learning processes which limited degrees of variation of vessel style, and thus clusters around a model-style. This system of learning is also inferred from the presence of systematic patterns of standardization of pottery production, as mentioned before, which requires the direction of a small group of specialized potters, which would infer the need for such a system of learning to exist. The absence of such a rigorous learning system in micro-style 1 vessels is supported by results from cluster analysis, PCA as well as MANOVA. Results show that micro-style 2 vessels are relatively much closer, and overlap to a great extent with vessels from stage 3. Potential interpretation of these results are that the micro-style 2 vessel style became the preferred style of choice for potters within the northern Kyushu region, and as such, the style continued and was transformed into the stage 3 type, while the micro-style 1 vessel style was abandoned.

However, without knowing which morphometric vessel variables were significantly changed over time, it is difficult to confirm whether or not this change from micro-style 2 vessels to stage 3 vessels reflect the true situation of the learning process, or simply sampling bias. Fortunately, MANOVA analysis supports the interpretation that the micro-style 2 vessel type was strategically chosen, and replicated through this learning process. MANOVA shows that the largest statistically significant changes in numerical values (counted in centimeters) over the entirety of the investigated period are within the “J,” height of neck and “H,” height between the largest width and neck. It just so happens that the largest difference in values between micro-style type 1 and type 2 is between these values, with type 1 vessels having long necks “J” and short body “H” values, and type 2 vessels having short necks “J” and long body “H” values. Thus, the general trend of these values, whether they get larger or smaller, should reflect the pattern of acceptance of one of these micro-styles in favor of the other. MANOVA results show that neck “J” values *significantly decrease* from 4.5 to 2.8 cm, and body “H” values *increase* from 2.5 to 3.6 cm. This general trend follows closely with the average factor scores of micro-style type 2 vessels. The combination of this analysis with cluster and PCA analysis shows that indeed micro-style type 2 vessels of the central Fukuoka plain were chosen as the desired vessel style, not only among the potters themselves, but also by the community as a whole, as Santacreu (2014) points out, that “users [of pottery] also participate in the reproduction of choosing” (Figure 13).

Further investigations into the source of differential intra-vessel variance between the upper and lower portions of vessels and why the lip/neck region shows consistently high degrees of variance is a future endeavor that will likely elucidate more detailed notions of agentic action during the formation process of pottery during this period. Tentative inquiries show that the lip/neck of pottery may show higher degrees of variance due to the conscious and idiosyncratic styles of potters, as compared to that of the lower body/base regions (Roux 2003). Furthermore, investigations by Gandon & Roux (2019) and Gandon *et al.* (2020) show that within standardized pottery producing communities in India, the upper half of vessels often takes the longest amount of time to create, with the highest number of unique and increasingly complex motor skills (as measured through hand gestures) needed to complete these sections is the highest between any other section of vessels. These notions show that even within standardized pottery producing communities, idiosyncratic style is still a measurable phenomenon, and as such, may have contributed to further regional styles within western Japan in later stages of the Yayoi period, as the “Yayoi culture” spread outside of the Northern Kyushu region (Miyamoto 2016).

4.3 Discussion conclusions

It has been understood that through a series of technological choices made not only by potters, but also by pottery consumers at the local level; certain styles of pottery production were chosen as desirable (micro-style 2), and as such were incorporated into the standardizing, methodically rigorous system of learning via a “tutor, learner and model” system. Styles that were not considered desirable (micro-style 1) were not incorporated into this system, and as such do not reflect a level of standardization around a model style, and were eventually disregarded completely in favor of the desired style (type 2), which continued into later phases (stage 3) (Figure 13). These styles are not only a reflection

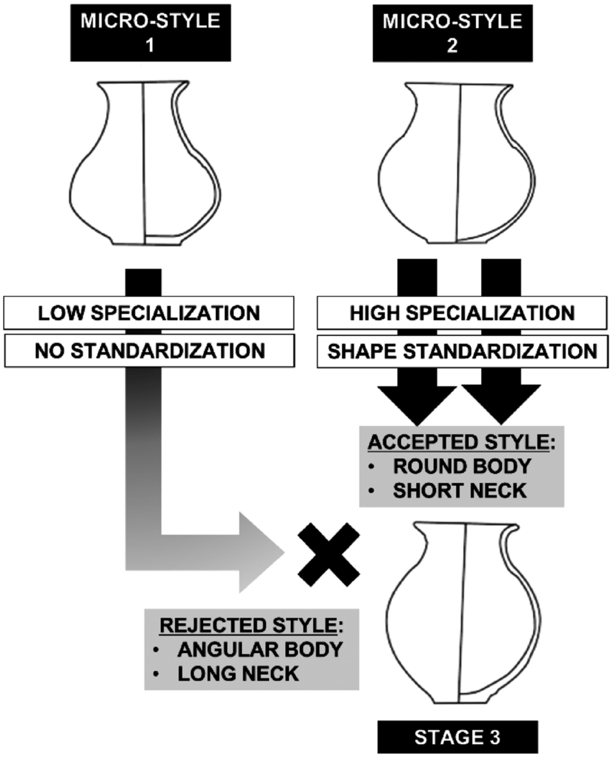

Figure 13. Process of pottery standardization from stage 2 to stage 3 vessels

of stylistic differences, but also incorporate different levels of technological choice, that being a direct reflection of certain social identities and systems of learning. As such, these styles reflect different conscious and unconscious human action reflecting these identities, engrained into the vessels themselves.

5. Conclusions

This current study was an updated summary of a master's thesis project and currently constitutes a small portion of a larger PhD research project, and as such, some of the views expressed currently along with the chosen analysis are susceptible to change as the project progresses. This current project sought to test how to overcome several large theoretical and methodological shortcomings present in the current study of Yayoi period earthenware. By combining methodological frameworks from a variety of traditions, it has been noted that the inclusion of both seemingly incompatible methods together were deemed very useful in this particular case study. Results have shown that through a lack of rigorous methodological testing, several important micro-regional complexities have been ignored in previous studies of pottery in the northern Kyushu region.

However, while in the current case, traditional distance-based morphometric analysis has proven successful in elucidating interesting differential morphological variance; the use of such methods within a material-cultural context should be done so with caution. As is the nature of material culture, distance analysis will often be overridden with a majority of size factors, such as widest width or height, that may obscure any notion of differential shape. While traditional methods are still utilized in modern analysis of biological samples, the setbacks of this method in archaeology has necessitated more complex incorporations of outline and 3D-based geometric morphometric analysis (Cooke & Terhune 2015). While the results shown above have elucidated exciting new directions for the expansion of methodological frameworks within pottery studies in Japanese archaeology; in further expansions to include morphologically distant shape types, this inclusion of non-distance-based techniques is a necessary evolution of this methodological process.

While this study exclusively focused on one shape type of pottery, the "tsubo," other shape types that were used in different social contexts may lead to several interesting clues as to not only the nature of the large spread of migrant culture into the Japanese archipelago, but also how local cultures accepted and rejected certain aspects of new traditions to create regionally distinct traditions that may have changed the course of regional diversity in the centuries to follow.

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