Identifying social learning mechanism in amphorae production within Roman Empire using multivariate methods ☆

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Abstract

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1. Introduction

Material culture allows to understand a part of the mechanism of the human behavior (Richerson and Boyd, 2005; Schillinger et al., 2016a). Thought material culture, we can observe cultural patterns which can explain how the culture evolve (Richerson and Boyd, 2005). This mechanism can be analyzed by the study of variability on material culture which can help to detect social learning patterns as, for example, how to teach and make an amphora. In archaeology, the detection of those patterns in the archaeological records could also explain whether these changes are produced by cultural reasons which varying over time and space (Basalla, 1988). As result, different information are shared by social learning generating an accumulation of knowledge which are transmitted from generation to generation in different context and content conditions (Eerkens and Lipo, 2005; Neff, 1992; Henrich and McElreath, 2003; Boyd et al., 2011). In any case, the mode of learning transmission along with several external con-

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ditions might affect directly or indirectly the pattern of manufacturing of the artefacts.

The detection of these patterns can result more significant in large-scale pottery productions when this production are increasing to satisfy the demand of more complex societies, as the case of Roman Empire. This huge of production allow us to detect some morphometrical variations to understand a part of the economic dynamic of Empire.

This paper explores the changes in the production processes during the Roman Empire. In particular, our study is focused on understanding the pottery-making techniques by analysing large-scale amphorae production in a specific area. In this case, an evolutionary framework (Mesoudi, 2015; Shennan, 2008a) is used for studying the implication and the impact that this production might involve on the evolution of social learning processes. Within evolutionary perspective, social learning is analysed to understand the production mechanisms in amphorae. Specifically, the aim of this study is understanding how the amphorae production were organized and whether it is possible to identify amphorae made in different workshops. Our main hypothesis concerns about understanding the modes of transmission of pottery-making techniques and how these techniques could have been transmitted in time and space.

Following a large number of authors (Cavalli-Sforza and Feldman, 1981; Hosfield, 2009), pottery production can be learned on different modes of cultural transmission depending on the level of production in the communities. Vertical transmission is a mode of transmission when the teaching of the production is done from master to disciple while in horizontal transmission individuals teach pottery techniques to others individuals within the same level and those workers spread the knowledge to their community (Epstein and others, 1998)

In material culture, artefact variation might be also affected by geographical distance (Björklund et al., 2010; Shennan et al., 2015; Van Strien et al., 2015) where material culture is more similar in close population who interacted each other. In other case, the correlation between both seems not visible due to different factors (Hart, 2012).

However, different debates revolve around how individuals or groups acquired and transmitted techniques skills (Bowser and Patton, 2008; Mesoudi and O'Brien, 2008). In addition, this challenge is combined with the difficulty of detecting the different modes of transmission in the archaeological record (Roux, 2015). In the case of archaeology, several studies have analysed this process focused on the production of handmade pottery (Steele, James et al., 2010) or stylistic variations (Neiman, 1995; Shennan and Wilkinson, 2001). Specifically our work pretends to inquire whether learning processes could be similar with a more standardized and massive production (Gandon et al., 2014), focused on the case of pottery production in the Roman Empire. In this work we have explored the transmission of these processes associated with amphorae production through a combination of empirical analysis and multivariate methods.

The paper can be sketched as follows. The next section introduces the case study and existing hypotheses, the third section will illustrate about the methods that we have applied to analyse our case study, the next section will deal about the results; and finally we highlight with a discussion about our results.

2. The amphoric production in Roman Baetica

Our case study examines the variation of the amphorae production located in *Baetica* province (currently Andalusia, south Spain). During the Roman Empire, a large-scale infrastructure of amphorae production was developed around this area to supply the provinces of the Roman Empire, with a huge impact during the supplying of the roman legions in places such as Britania (Funari, 2005; Carreras Monfort, 1998) or Germania (Remesal, 1986). For this reason, this ancient province became in an important support for the production and distribution of olive oil to the rest of the Empire from Ist to IIIrd centuries Chic (2005); Berni (1998); Remesal (1998). *Baetica* had also a strong connection thought rivers that allowed developing an important trade network mostly around the Mediterranean (García Vargas, 2010). As result of this increase, more than 90 pottery workshops were currently located along the Guadalquivir river and its tributaries. The majority of amphorae produced in this area belong to *Dressel 20* divided into different typologies, according with different authors (Berni Millet, 2008; Martin-Kilcher, 1994). This amphora type was used mostly to transport olive oil for around 300 years in order to satisfy the demand within Roman Empire (Remesal, 1977). In particular, olive oil was a significant product frequently related in different aspect of the roman daily life such as consumption, lighting and hygiene (Mattingly, D.J., 1988).

The importance of this commerce is also showed by the fact that Dressel 20 amphorae production was identified with different marks about its provenance although the meaning of the actors in this process seems not clear (Rubio-Campillo et al.). Thus, this amphorae production was a particular example of production strategy that experimented few changes around three centuries. In any case, our main question will be related to understand how the amphorae workshops were organized in *Baetica* area and the transmission of the production techniques by potters. Thereby, technological knowledge could have been transmitted by vertical transmission where technical knowledges is learned to master to apprentice and thus continuously. When vertical transmission predominates in this process over horizontal transmission then amphorae made in nearby workshops might share more similar traits than amphorae made from farthest workshop. Otherwise whether horizontal transmission is the main transmission in this process the social learning would be transmitted by workers. Then there would not be differences among workshops on the production. In our case, we can detect measurable differences among this type of amphorae correlated with the geographical distance.

3. Material and methods

We collected a dataset of 470 amphorae from 5 different workshops excavated in order to identify the social learning process that tooks place in the case study. The workshops were located in Malpica (Palma del Río, Córdoba), Cerro del Belén (Palma del Río, Córdoba) (Díaz Trujillo, 1992), Parlamento (Sevilla) (García Vargas, 2000), Villaseca (Córdoba)(García Vargas and Morena, fourthcoming) and Las Delicias (Écija, Sevilla) (Fernández et al., 2001; Mauné et al., 2014) (see map 1).

Figure 1: Dressel 20 workshops were mostly distributed along the rivers Gualdalquivir and Genil. Location of the five workshops analysed in this area.

We created a dataset where were selected 413 amphorae related to the selected chronology, 80-100 samples of each pottery workshops. The choice of these workshops corresponded to several reasons. Firstly, the workshops were selected from different spaces in order to analyse the production patterns depending on the distance of each workshop. Secondly, the extended chronology of these workshops serves as proxy to examine changes on the variation shape. In our case, the type Dressel 20 did not experimented especially visible changes on the production pattern during almost three centuries (Berni and García Vargas, Enrique, 2016). Finally, the workshops selected were open excavated and provided a large number of materials.

Eight different measurements were taken for each amphorae sample of the 5 workshops studied. The measurements were focused on the rim sherds whose fragments were the most preserved on the archaeological sample. In the case of pottery attributes, rim sherds and the curvature of handles work as an useful indicators of variability (Berni Millet, 2008). The measurements were divided into exterior diameter, inside diameter, rim height, rim width, shape width, rim inside height, other rim width and protruding rim, as the Fig 2 indicates. The method required a large sample size and for this reason the test was focused on rim sherds. Other significant parts such as handles and bases were found in lesser quantities thus compromising the applicability of the method due to small sample size.

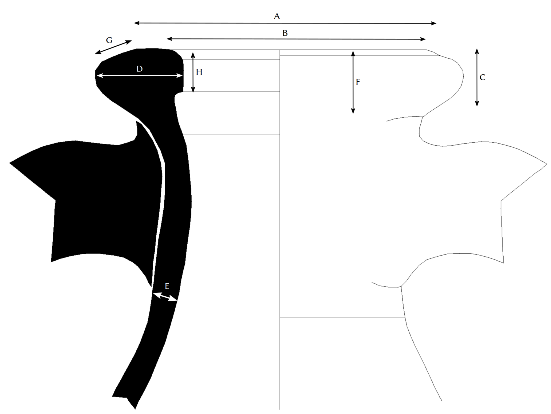

Figure 2: Example of the 8 measurements taken for the sample in order to provide morphometric data. A: external diameter. B: inside diameter. C: Rim height. D: Rim width. E: shape width. F: rim inside height. G: rim width 2. H: protruding rim

In our study, we have selected five variants according with three centuries (Dressel C: I-II; Dressel D: II; Dressel E: III). Without important variations in three centuries, the chronology respond to a relative dating obtained by the classification identified on shapes in different studies defined by defined by P. Berni (Berni Millet, 2008) and Martin Kilcher (Martin-Kilcher, 1994). All of the variants selected were found in excavations from the proper workshops studied in order to avoid some material which can contaminate the sample. For the proposal of this study, the rest of variants were not taken into account from our study by not having enough material for the analysis.

3.1. Principal Component Analysis

The sample selected were analysed using statistical method such as Principal Component Analysis and Discriminant Analysis to explore these metrical differences on the rim sherds. We used Principal Component Analysis (PCA) to simplify the large number of variables in our dataset. This method allows to capture the most of variation from our dataset and create a reduced number of new variables without losing relevant information (Jolliffe, 2002; Shennan, 2008b). Moreover the new set of variables contain all the data information expressed as the result of the most variance from the original variables. This method is commonly used in archaeology for the study of the variation of material culture (Li et al., 2014; Schillinger et al., 2016b). In order to apply a degree of uniformity, we created a training dataset of 210 samples. In our study, PCA allowed to capture the most variation of the measurement and retained into two first principal components.

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3.2. Discriminant Linear Analysis

The variability of the first 2 Principal Components was used to cluster our dataset using Linear Discriminant Analysis (LDA). LDA will be conducted to find significant differences among workshops by the combination among variables obtained for the first principal components. LDA identifies which variables allow to distinguish each group and how many variables are necessary to achieve the best combination as possible. Thus, LDA is used to explore a better separate training set from the results of the most relevant principal components. In our dataset, the first principal components produced by the amphora measurements are grouped into each workshop groups and are separated to obtain a better discrimination among groups. We also generate a Confusion Matrix (CM) to able of quantifying the degree of confusion and compare the index of similarity among workshops. CM calculated the probability of success and error of the results. It generates a matrix where higher value are the results of an incorrect classification. As example, this method has been commonly used to detect differences in artifact production (Charlton et al., 2012; Thorpe et al., 1984), and particularly for a similar study about pottery production in *Tarraconense* (Aguilera, 1998)

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3.3. Distance

The morphometric distance generated with the results of DA will be compared with the geographical distance to prove if exists a correlation between each other. Euclidean distance will be used to measure the distance among workshops. We think that workshops with a result of morphometric distance minor would be closer on spatial distance.

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4. Results

The morphometric variation on amphorae production was analysed to quantify the technical differences on the pattern production among workshops. The analysis of PCA produces a set of values for each variable observed. Variables show how much variability exist in the dataset grouped by each principal components. The results, indicated in the Table 1, show the most differences were focused on the protruding rim and rim width 2.

The patterns observed in the first 2 Principal Components were plotted to visualize the degree of variation by isolation among workshops. The results suggested than amphorae from closer workshops tend to be more similar than amphorae made in furthest workshops. In particular, the Fig 3 illustrates how the four closest workshops show variation on PC1 (i.e. Belén, Delicias, Villaseca

Variables	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
Exterior diameter								
Inside diameter								
Rim height								
Rim width								
Shape width								
Rim inside								
Rim width 2								
Protruding rim								

Table 1: 8 principal components

and Malpica) while Parlamento displays a distinctive pattern than the rest of workshops on PC2 values.

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
Eigenvalue								
Proportion								
Cumulative								

Table 2: Result values from Principal Component Analysis

Discriminant Analysis was used to analyse the results obtained from PCA. xavi: y ya esta? Creo que haria falta ilustrar un poco mas los resultados del DA.

A training set of 210 samples were analysed assuming the workshops as 5 groups (”belen”, ”delicias”, ”malpica”, ”parlamento” and ”villaseca”) For the analysis, a total of 93 were classify correctly while 113 were classify incorrectly, as shown the Fig 4. The results showed a similarity in three groups while two groups depicted a different pattern. This could be caused by the geographical proximity among these workshops. maria: hablar de prediccion incorrecta y correcta

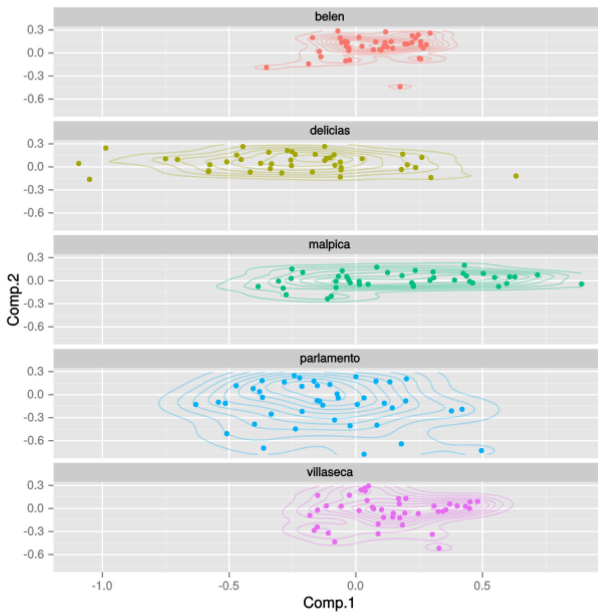

Figure 3: First and Second Principal Components for the amphorae measurement dataset from the 5 workshops analysed

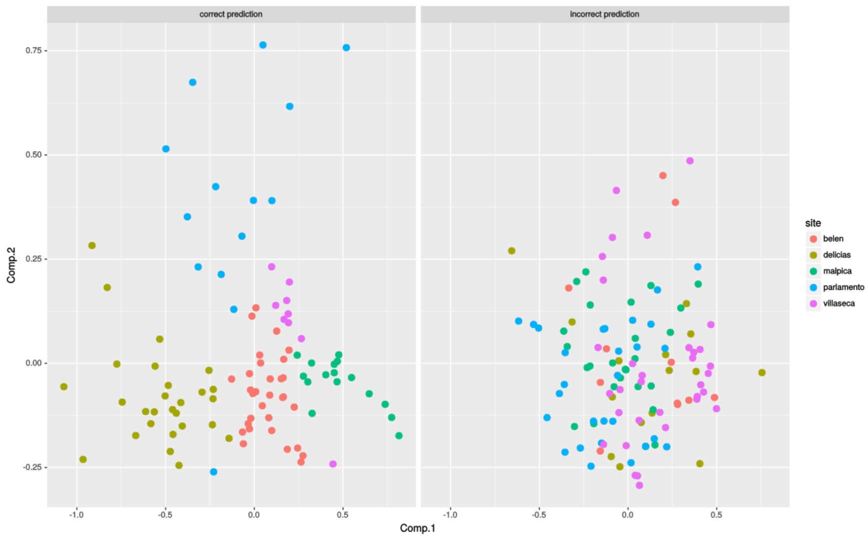

Figure 4: Plot with the correct and incorrect predictions result of Discriminant Analysis

The results of Confusion Matrix proved that workshops with more troubles to be distinguished such as Malpica and Belén due to the similarity on the results share a minor geographical distance than the rest (see Table 3). Classification test with the whole dataset gave an accuracy percentage of 50.61%. Applying this to a training dataset reduced the accuracy to 46.19%.

Therefore, spatial distance could be inversely correlated with making techniques processes of amphorae in the case of *Baetica* area.

	Belen	Delicias	Malpica	Parlamento	Villaseca
Belen	31	6	12	11	13
Delicias	2	27	6	13	1
Malpica	6	4	16	2	13
Parlamento	3	2	3	14	6
Villaseca	0	3	5	2	9

Table 3: Confusion Matrix with rows pointing out the workshops analysed. The sample analyzed gave an accuracy percentage of 46.19 %. Results of P.Value <0.01.

4.1. Distance

We compared morphometric and spatial distance by performing peer-to-peer analysis between all the workshops. We calculated the geographical distance generated by the Euclidean distance between each site and the distance among amphora measurements, calculated using the previous results. The workshops were chosen with different distance in order to prove the correlation between spatial distance and variability of the amphorae. Distance Matrix (see Table 4) shows the results of the analysis of morphometric distance. The workshops with morphometric distances lower tended to be more similar than the rest. The results of the analysis were compare with the real geographic distance, shown in the Fig 5. Here morphometric distance of the amphorae are strongly correlated with the spatial distance of workshops. When geographic distance is lower as the example of Belen and Malpica the morphometric distance is more similar whereas when distance is higher, as Parlamento, the morphometric distance display differences with the rest of workshops. Thus, the results suggest a variability on the making-techniques processes might depend on the spatial distance.

	Belen	Delicias	Malpica	Parlamento	Villaseca
Belen		0.8409091	0.7272727	0.7857143	0.7169811
Delicias	0.8409091		0.7522523	0.7023810	0.8018868
Malpica	0.7272727	0.7522523		0.7142857	0.6509434
Parlamento	0.7857143	0.7023810	0.7142857		0.7380952
Villaseca	0.7169811	0.8018868	0.6509434	0.7380952	

Table 4: Results of matrix distance among workshops

5. Discussion and Conclusion

Differences on the making techniques processes among workshops show a variability correlated with spatial distance. The analysed morphometric traits suggest that the similarity between amphorae decrease with the spatial distance

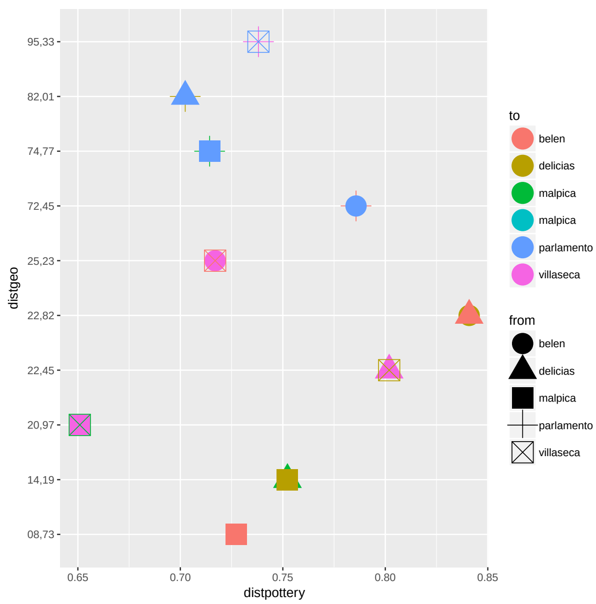

Figure 5: Plot with the results of the comparison between morphometric distance and geographic distance (km)

between the workshops where they were produced. As result, amphorae made in nearby workshops with a minor spatial distance share more traits than amphorae made in pottery workshops furthest. In other words, the variability on the making techniques processes between closer workshops was difficult to differentiate. In our case, Malpica and Belén workshops where the geographical proximity are the closest shared more traits in comparison with other workshops (Parlamento and Las Delicias). Thus the probability of interaction between workshops is increasing when the proximity is closest while this likelihood decreases when the possibility of interaction is low.

We have observed than rivers courses could have affected in the transmission factors. In the case of the commerce, rivers and its tributaries played an important role for the transport of goods. The huge demand within Roman Empire and the good conditions for the loading and unloading of products (Bevan, 2014) might have influenced the mode of transmission due to the continuous contact between workshops.

The results suggest also that vertical transmission could be the main cultural mechanism to explain the variability between workshops. The different morphological traits among workshops seem proper of a low contact between potters from others workshops. The evidenced confirms therefore that these techniques traits were transmitted with high fidelity and only with few changes during three centuries. It would mean that the disciples could have remained the making techniques processes in the workshops where they were trained.

By contrast, horizontal transmission doesn't seem to be the most probable process. The continuous contact between potters from different places had generated a more homogeneity in the technical practises. Workshops were sharing the same production techniques. As result, it would generate a social network where potters with the same social learning level worked in different workshops at the same time. Our result suggest a progressive contact with closer workshop instead. Moreover, the fact that isolation by distance is detected suggests a limited displacement between distant workshops. Thus, vertical transmission would be explained with this observed process. However, the diversity of social learning processes are clearly complex. In other words, the transmission of knowledges between master and disciple did not discard that horizontal transmission played an important role in this process as well. It can be a process where this vertical transmission dominated at first in the same workshops but consequently this transmission would be affected by workers who exchanged ideas or workers moving to other workshops.

The combination of empirical analysis with the statistical methods have provided a strong baseline for a better understanding of the amphorae production in the Roman Empire. These methods offer also an strong complement to other methods as archaeometry for the characterization of production sites and places of consumption.

We have identified measurable differences in the techniques by observing and we have tested these particularities using multivariate methods. Our analysis provides an useful baseline for the exploration of the social learning processes related with amphora production in the Roman Empire. Hence, the results have lightened to understand the link between social learning and archaeological evidence in a diversity of scenarios.

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