Unsupervised and Supervised Classifications of Egyptian Scarabs Based on the Qualitative Characters of Typology

Sergio Camiz[1] and Sara Venditti[2]

[1]Università di Roma “La Sapienza” Dipartimento di Matematica “Guido Castelnuovo”
[2]Dipartimento di Matematica “Guido Castelnuovo”
sergio.camiz@uniroma1.it

Abstract. This paper discusses statistical techniques for the classification of Egyptian scarabs.

1. Introduction

Egyptian scarabs with Thutmosis III name (Menkheperra, Figure 1) engraved on the bottom were produced during centuries, so that the dating of examples of unknown provenance cannot be based on the engraved pharaoh’s name. For this reason, the dating should be based on different criteria. In her MA thesis, Andrenucci (1996) raised the problem and showed a possible solution, based on Jaeger (1982) dating criteria: she defined a special coding of the details carved on the scarab shape, and used a weighted clustering technique that seemed to give acceptable results.
Notwithstanding the quality of the results, the used procedure seems too arbitrary, both in some aspects of the coding and in the clustering technique. In particular, the latter uses the numerical coding of the non_ordered different modalities of each character without any justification of this choice. As a consequence, the clustering model, albeit apparently effective, does not help in the explanation of the different scarab features along the time, nor this technique may be applied to other corpora. For this reason, on the occasion of Sara Venditti (2003) MA thesis, we decided to follow a different pathway, aiming at investigating to what extent the Jaeger (1982) dating could be estimated based on the Andrenucci (1996) coding of the morphological characters, and to define some classification functions that could be used to date some scarabs with unknown dating.
Our procedure is based on exploratory data analysis techniques, with some aspects of confirmatory techniques, in order to validate what the explorations outlined. The results seem in some respect contradictory, as it will be discussed in the last section.

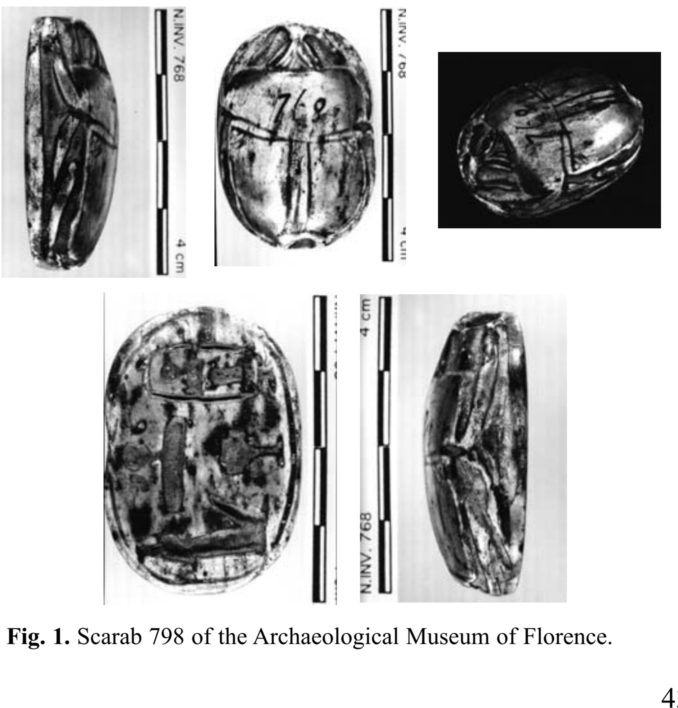

Fig. 1. Scarab 798 of the Archaeological Museum of Florence.

2. Data and Analysis Methods

The corpus of scarabs studied by Andrenucci (1996) is composed by 80 Menkheperra scarabs of known date and 90 scarabs with other names of the same periods. For the coding, Andrenucci referred to the previous attempts at coding (Rowe, 1936; Martin, 1971; Ward, 1978; Jaeger, 1982; Tufnell, 1984) and chose 22 different features of the scarabs, such as the shape and the height of the head, the shape of the eyes, the kind of paws, etc.. Each of them was coded according to 4 to 8 different modalities of the carving.

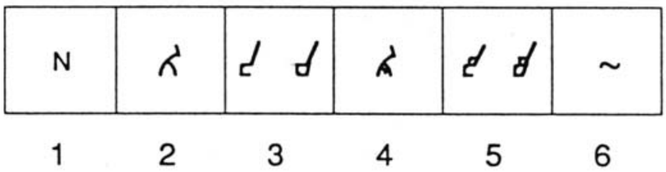

Fig. 2. The coding of the eyes of the scarabs, as coded by Andrenucci (1996).

As an example, the scarab’s eyes, shown in Figure 2 are coded as: 1) no eyes, 2) single inner, 3) single outer, 4) double inner, 5) double outer, 6) other, 7) not coded.
As for the 170 scarabs with known dating, five different periods were taken into account for 146 scarabs that Jaeger dated, according to his criteria: 1) Thutmosis III (17 scarabs); XVIII dynasty (38); Ramessid period (59); III intermediate period (17); Late period (15). Further 24 scarabs had a less precise estimated dating, including a span of time longer than one of the said periods, so that they were given a special coding.

Unlike Andrenucci, who used the qualitative coding assigned to the modalities as if it were quantitative, we faced the problem of using the qualitative characters as discriminant. This is not a classical technique, since the classical discriminant analysis can be applied only to quantitative characters. Then, we decided to rely first on exploratory data analysis techniques, that could give us an idea of the relations among characters and periods. To see if any factor could be associated to diachronic evolution, Multiple Correspondence Analyses (MCA; Lebart et al., 1995) was used, followed by an Ascendant Hierarchical Classification (AHC; Gordon, 1999) based on the first three interpreted factors and built considering Ward method on Euclidean distances among units; as stopping rule we used the one proposed by Kalinski and Harabász (ibid.). In fact, the time periods were projected on the axes as supplemental elements. In order to check if the position of the time periods was significant on some factor, we tested if their coordinates were significantly different from zero, under the null hypothesis of random distribution. We also tested if any modality was typical of one period: with typical we mean that the frequency of a modality in a group of units is significantly higher or lower than the frequency expected by the hypergeometrical law, the law that rules the presence of k objects of one kind out of n randomly extracted, if in the population of N objects there are K of that kind. As significance level, the usual 5% of probability was chosen. The same test was used to check if any period could be typical for the groups built by the AHC.

To proceed further in the process of classification, we applied two different techniques: a Segmentation (Celeux and Nakache, 1994), aiming at creating a decision tree, based on the characters modalities, to correctly attribute the scarabs to their period, and a Qualitative Discriminant Analysis (QDA; Saporta, 1975), aiming at identifying classification functions, able to automatically assign the scarabs to their appropriate period.

The rationale of the two methods is different: the segmentation aims at enabling the attribution of a unit to a class based on a set of binary rules forming a binary tree, such as "If a unit has the modalities ai, ah, ..., ar of the character A, then it is likely to belong to the classes bj, bk, ..., bs of B, else to any other one". So, to each rule are associated two classes partitioning an already existing one. These rules are found iteratively as those that minimise the risk of bad attribution of a unit to a wrong class. The Discriminant Analysis (DA; Romeder, 1973; Hand, 1981) aims at providing linear classification functions, one for each class. In order to build these functions, discriminant analysis represents the units in a special Euclidean space, whose coordinate orthogonal axes optimally separate the classes, that is each class centroid (the point whose coordinates are the average of the coordinates of the units belonging to the class) is furthest from all other classes centroids. In such spaces, the Euclidean distances of each unit to all classes centroids are calculated and the units can be attributed to the class whose centroid is nearest. This could as well be transformed to a probability, so that the units are attributed to the class whose classification function is highest.

It is clear that DA is not suited for qualitative characters, such as the shapes of the segments carved on the scarabs. To overcome this problem, we applied the QDA, developed by Saporta (1975). It is based on the principle that a qualitative data table can be completely rebuilt using all factors of its MCA. Thus, in QDA, DA is applied to the MCA factors, giving the representation of the units on discriminant factors and the classification functions are then transformed using the relations among factors and characters' modalities, in order to allow the classification based on the 22 characters modalities. For the segmentation, the CART method (Breiman et al., 1984; Celeux and Nakache, 1994) was used. This method builds a binary tree, so that at each step a binary partition of a group is done according to one character, so that the two formed classes are most homogeneous: with this we mean that the group is split so that all units with some modalities are in one class and all other are in the other. The iterative process stops when no further partition is possible. Then some subtree is suppressed if it gives no sufficient information, thus giving some optimal or suboptimal tree. In order to experiment QDA efficiency, we tried different criteria to build classification functions, in particular reducing the number of characters, since reducing the number of extracted factor could not be easily used nor interpreted. The first discriminant analysis took into account all factors extracted by MCA performed on all characters. In the following the characters were reduced according to the significance of their contribution either to the increase of the chi-square or the cumulate Tchuprow coefficient (Saporta, 1990), a transformation of the chi-square, ranging from zero to one.

Most computations were done using SPAD package, release 4 (Lebart et al., 1999); only QDA was performed with the specific program DISMOD (courtesy of Claude Langrand).

3. The Results

After some experimentation, the most interesting MCA was performed considering active all the characters describing the typology, only removing the modalities absent or present in only one scarab, and only the scarabs with known dating period. In this analysis the first factor is accounted for 60% of the total variation (re_evaluated according to Benzécri, 1979), the first three summarise over 76%: this can be considered a very good performance.

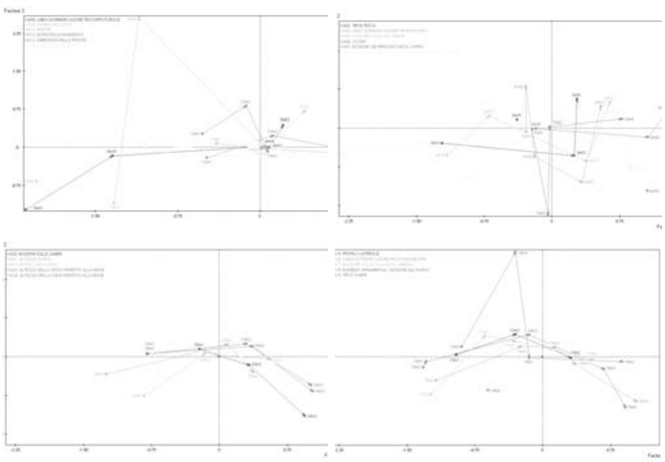

Fig. 3. The pattern of the 22 characters on the plane of the first two factors of Multiple Correspondence Analysis.

Along the first factor (Fig. 3), most characters show a regular pattern, with a little Guttman effect that inflects both the modalities pattern and the units in an arch shape (Fig. 4).

As a result, one can consider the first coordinate of each modality as an optimal coding for a unidimensional coding of the modalities. We drop here any tentative interpretation of the second axis, since the Guttman effect would claim for a continuous unidimensional variation of the carving style of the scarabs, that could be attributed to the time evolution.

Unfortunately, the periods on the plane of first two factors (Fig. 5) show an irregular pattern: the first two periods are on the right side of the first factor and the other three on the left one, but on each side the order of the periods is not coherent, so that one may wonder to what extent the different periods are effectively described.

In fact, the hierarchical classification, confirms these doubts. Considering the partition into six classes as the most suitable, the classes can be characterised as follows, on the basis of the shape of the carvings:

Class 1 (25 scarabs): well separated head and tail, very well carved paws, rounded side profile, V-shaped side callosities, very curved back with backwards unbalanced profile; half of these scarabs were dated to the XVIIIth dynasty.

Class 2 (24 scarabs): not well separated head and tail, V-shaped incision on shoulder callosities.

Class 3 (27 scarabs): inner eye-sockets, double inner eye, round head, V-shaped incision on shoulder callosities, well outlined paws, well separated head, semicircular outline of the top of the head, rounded convex division between forehead and clypeus, horn represented by two vertical lines; a quarter of them were dated to the Thutmosis III period.

Class 4 (28 scarabs): round head, average curved back, rounded concave division between forehead and clypeus, no incision on shoulder callosities; 28% of these scarabs belong to the late period.

Class 5 (46 scarabs): head and tail attached to the basis, flat back with many carvings, trapezoidal head, no eyes nor orbits, no carvings on shoulder callosities, no incisions to represent the horn, straight jaws, straight side profile; half of these scarabs belong the Ramessid period.

Class 6 (20 scarabs): head and tail attached to the basis, trapezoidal head, no distinction between chest and elytron, single curved incision on shoulder callosities, straight side profile, straight jaw edges, flat back with forward unbalanced profile.

In the convex hulls of the classes are represented as contour of the belonging scarabs. Into each class, the image of a scarab closest to the centroid is represented, thus giving an idea of the style of the scarabs of the class. Apparently, the relations with the suggested dates do not seem very strong. This is confirmed by the period characterisations on the basis of the shape and carving features, which give the following results:

Thutmosis III (17 scarabs): orbits inside the head.

XVIII dynasty (38 scarabs): head and tail well separated from the basis, well carved paws, V-shaped incision on shoulder callosities, backwards unbalanced back, rounded side profile, rounded convex division between forehead and clypeus.

Ramessid period (59 scarabs): tail attached to the basis.

III intermediate period (17 scarabs): no typical character.

Late period (15 scarabs): no carving on shoulder callosities.

It is clear that, based on these few modalities, one cannot expect to get a reliable dating of the undated scarabs. In fact, the following analyses, segmentation and QDA, reflect this problem. Both were performed only on the 146 scarabs whose date was known.

The default use of segmentation procedure, as suggested by SPAD, suggests to limit its use to only two terminal segments, that thus could not distinguish more than two classes, namely the XVIII dynasty and the Ramessid period, according to whether the tail was raised or not on the basis. In this case, the percentage of good attribution is quite low: 47.26%. Then we decided to raise the number of segments to 29 and 37, obtaining much higher percentages of well placed items, 82.19 and 86.30% (Table 1), but paying the cost of very complicate sets of rules.

These results must be compared with those of QDA. In this case, two indices can give information on the quality of the analysis: the chi-square of the reconstruction of the table based on the first MCA factors, and the cumulate Tchuprow coefficient. The first one can be used to reduce the dimension of the factors solution, since one can drop the factors that do not contribute significantly to the increase of the chi-square of the rebuilt table. The cumulate Tchuprow coefficient informs about the relation among the character to be explained and the set of characters used to explain it. Indeed, it increases as new explicative characters are taken into account, according to the increase of information due to the introduction of a new character. Thus, sorting the characters in the decreasing order of Tchuprow coefficient, we tried to reduce the number of characters involved according to the maximum number of characters with significant chi-square, or to over 99% or 95% of the total cumulate Tchuprow coefficient. Instead, the attempt to reduce in each analysis the number of factors limiting to those greater than the average, as suggested by

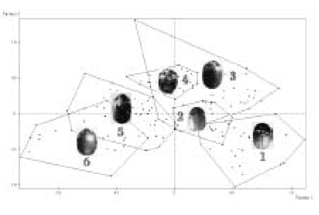

Fig. 4. The pattern of scarabs on the first plane of MCA, with classes contours and most typical scarabs.

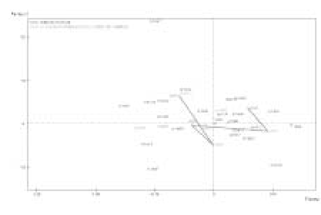

Fig. 5. The trajectory of the time periods on the first plane of MCA.

Attributed	29 segments: 82.19% (41.70%)						37 segments: 86.30% (37.67%)				
Original	1	2	3	4	5	Original	1	2	3	4	5
1	12	3	2	0	0	1	12	3	2	0	0
2	2	33	2	1	0	2	2	33	2	1	0
3	0	3	55	0	1	3	0	3	55	0	1
4	1	1	3	12	0	4	1	2	2	13	0
5	0	0	7	0	8	5	0	0	2	0	13

Table 1. The attributions of the scarabs according to two possible segmentations of the scarabs.

Benzécri (1979) resulted very difficult to use, due to some limits of the software. Thus, the four different QDA performed were the following, with the given percentage of well classified items:

- all 22 characters: 62 factors, well classified = 80.82%;
- only 17 (significant chi-square): 49 factors, well classified = 73.97%;
- 16 (99.39% of cum. Tschuprow coef.): 47 factors, well classified = 71.23%;
- 10 (95.71% of cum. Tschuprow coef.): 30 factors, well classified = 65.75%.

In Table 2 the attributions of the scarabs are shown, according to the worst QDA (4) and the best one (1). This gives results similar to the worst segmentation. In all cases, the interpretation of the results, in terms of the style of the scarabs according to the period seems very difficult to obtain.

	Attributed by 4)						*Attributed by 1)*				
Original	1	2	3	4	5	Original	1	2	3	4	5
1	11	2	2	1	1	1	13	3	1	0	0
2	4	29	3	0	2	2	4	31	2	1	0
3	7	6	35	6	5	3	6	3	45	2	3
4	2	3	1	11	0	4	1	1	0	15	0
5	1	0	3	1	10	5	0	0	1	0	14

Table 2. The attributions of the scarabs according to two qualitative discriminant analyses.

4. Conclusions

The attempt to use qualitative segmentation and discriminant analysis as tools for the dating of the scarabs, based on a very classical coding and suitable analysis tools, gave good results, but very difficult to be interpreted, due to the great number of modalities and characters involved. It is a pity that a quantitative comparison with the results of Andrenucci (1996) is not possible, since no information is given on the correct attributions of her method.

Considering the analysis methods, we think that further investigation on the segmentation techniques could be helpful in the quest for a better procedure. Concerning QDA, it is clear that a better synergy of MCA and QDA should be implemented. In fact, in DISMOD the underlying MCA is only a tool for the discrimination, so that all interpretation aids present in the specialised software are not present. This is a drawback, since facilities as the selection of the modalities, the information on the contributions of both modalities and units to the factors, the re-evaluation of eigenvalues, etc., all enabling a more aware selection of both characters and factors to take into account, could greatly improve the selection of a more parsimonious discriminant model.

Anyway, some final comments can be done. We think that the coding, as proposed by Andrenucci, is quite adequate for the description of the scarabs style. On the opposite, since at first sight the idea of a seriation of the scarabs according to the style diacronic evolution seems effective, one may wonder if the dating of the scarabs, based on Jaeger criteria, was reliable. This could be checked by looking at the scarabs, but even if we had their images, we are not sure that we could fulfill the task effectively. Supposing the given dating reliable, then one should think that the style variation may depend on other factors, that could be profitably investigated. As we are not specialists in scarabs, nor even in Egyptology, we cannot imagine to answer these questions. For this task, a specialist is needed and his advices would be gratefully accepted, to interpret our results and cooperate to our deepening of the subject.

Acknowledgements

The scarabs data were given by Sara Andrenucci, the program DISMOD was given by Claude Langrand, the scarab images were found by Eleonora Ferrazza. Their valuable contributions are gratefully acknowledged.

References

Andrenucci, S., 1996. Gli scarabei Menkheperra del Museo Egizio di Firenze, con un saggio di classificazione e datazione, Tesi di Laurea, Università di Pisa.

Benzécri, J.-M., 1979. “Sur le calcul des taux d’inertie dans l’analyse d’un questionnaire – addendum et erratum à [Bin. Mult.] [Taux Quest.]”, *Les Cahiers de l’Analyse des Données* 4(3), 377–378.

Breiman, L., Friedman, J. H., Olshen, R. A., and Stone, C. J., 1984. *Classification and Regression Trees*. Belmont (California), Wadsworth.

Celeux, G. and Nakache, J.-P., 1994. *Analyse Discriminante sur variables qualitatives*, Paris, Polytechnica.

Gordon, A. D., 1999. *Classification*, London, Chapman and Hall.

Hand, D. J., 1981. *Discrimination and Classification*. New York, John Wiley and Sons.

Jaeger, B., 1982. *Essai de classification et datation des scarabées Menkhéperrê*. Fribourg (Suisse), Orbis biblicus et orientalis, Series archaeologica 2.

Lebart, L., Morineau, A. and Piron, M., 1995. *Statistique exploratoire multidimensionnelle*. Paris, Dunod.

Lebart, L., Morineau, A., Lambert, T. and Pleuvret, P., 1999. *SPAD - Système Pour l’Analyse des Données*. Paris, Cisia-Ceresta.

Martin, G. T., 1971. *Egyptian Administrative and Private Name Seals*. Oxford, Griffith Institute.

Romeder, J. M., 1973. *Méthodes et programmes d’analyse discriminante*. Paris, Dunod.

Rowe, A., 1936. *A Catalogue of Egyptian Scarabs, Scaraboids, Seals and Amulets in the Palestine Archaeological Museum*. Cairo, Imprimerie de l’Institut Francais d’Archéologie Orientale.

Saporta, G., 1975. Liason entre plusieurs ensembles de variables et codage de données qualitatives, Thèse de troisième cycle. Université Pièrre et Marie Curie, Paris VI.

Saporta, G., 1990. *Probabilités, Analyse des Données et Statistique*. Paris, Technip.

Tufnell, O., 1984. *Studies on Scarab Seals, vol. II: Scarab Seals and their Contribution to History in the Early Second Millennium BC*. Warminster, Aris and Phillips.

Venditti, S., 2003. Tecniche d'analisi multidimensionali dei dati per lo studio di scarabei egizi. Tesi di Laurea, Università di Roma La Sapienza.

Ward, J. H., 1963. Hierarchical Grouping to Optimize an Objective Function. *Journal of the American Statistical Association* 58, 236–244.

Ward, W. A., 1978. *Studies on Scarab Seals Volume 1 Pre_12th Dynasty Scarab Amulets*. Warminster, Aris and Phillips.