Journal of Archaeological Science (1996) **23,** 473–484

The Statistical Analysis of Artefacts in Graves: Presence and Absence Data

Bryan F. J. Manly

Department of Mathematics and Statistics, University of Otago, P.O. Box 56, Dunedin, New Zealand

(*Received 9 July 1994, revised manuscript accepted 5 June 1995*)

The analysis of artefacts found in burials is discussed in terms of the presence and absence of particular types, with some emphasis on new computer intensive methods of analysis. The questions addressed concern whether the artefact distribution appears to be random, the relationships between the different burials, the relationships between the different types of artefact, and whether the artefacts present in burials are related to sex and age. To focus the discussion, data from Khok Phanom Di, a Neolithic cemetery, are used for an example. There is evidence that co-occurrences of different artefacts are not what is expected from a null model of randomness, there are clear patterns in relationships between both burials and different types of artefact, and the proportional occurrence of different artefacts varies with the sex and age of the deceased.

Keywords: CLUSTER ANALYSIS, COMPUTER INTENSIVE METHODS, MORTUARY VARIABLES, NULL MODEL, ORDINATION, RANDOMIZATION TESTS.

Introduction

This paper reviews statistical methods that can be used to analyse prehistoric mortuary data. It is restricted to the consideration of the presence and absence of artefacts rather than counts of the number of times that each artefact occurs because occasional very high counts might bias conclusions. The analysis of artefact counts will be addressed in a later paper.

There has been interest in the statistical analysis of artefact data for over 25 years, stimulated by the increasing availability of the computers and software needed to do the required computations. Early work is summarized in the proceedings of a conference edited by Hodson, Kendall & Tautu (1971); see also Doran & Hodson (1975), Chapman, Kinnes & Randsborg (1981), O'Shea (1984), Bech (1988) and Nielsen (1988), for more recent examples. Some of the methods discussed here are not new in this application. However, there is emphasis on computer intensive methods that will not be familiar to most readers.

An example set of artefact presence and absence data is shown in Table 1. Here the site is the Khok Phanom Di cemetery in Chonburi Province, Central Thailand (Higham & Bannanurag, 1990, 1992; Higham & Thosarat, 1994). There are 153 burials, which accumulated over half a millennium from about 2000 BC. The burials are labelled from 1 to 154, including two infants in the same grave (5a and 5b), but with burials 148 and 149 excluded because they were only partially recovered. They contain among them 17 different types of artefact labelled A to Q. Information is also provided on the estimated age and sex of each of the deceased. Most infants were probably stillborn, but have been assigned an age of 0·1 years (1 month). Further information is available, such as tooth evulsion patterns, the presence of a shroud, and the chronological ordering of the burials, but this is omitted in order to keep the discussion as simple as possible.

Some of the questions posed by the excavators with respect to the artefact distribution at Khok Phanom Di are:

(a) Is there evidence that certain artefacts covary, either positively or negatively? That is to say, do certain artefacts tend to occur together, or are certain artefact combinations absent or rare?
(b) How can the presence and absence data best display which burials contain similar artefacts, and which artefacts have similar distributions over burials?
(c) How can the data be analysed so as to show most clearly the relationships between the different burials in terms of their contents?
(d) How can the data be analysed so as to show most clearly the relationship between the different artefacts in terms of their distributions in burials?
(e) How are grave good assemblages related to age and sex?

Testing Randomness of Artefact Combinations

To examine whether artefact combinations appear to be random, a method that has previously only been

0305–4403/96/040473+12 $18.00/0

Table 1. Presences (1) and absences (0) of 17 different types of artefact in 153 burials from Khok Phanom Di cemetery. Information is also provided on the estimated age of the body in years and the type of body (1, male; 2, female; 3, child; 4, infant)

Burial	Age	Sex	Artefacts ABCDEFGHIJKLMNOPQ
1	9·0	3	00000000100000111
2	0·8	3	00000000000000001
3	0·3	3	10000100100000001
4	26·0	2	00000000000000110
5a	0·1	4	00000000000000000
5b	0·1	4	00000000000000000
6	9·0	3	10000100000000100
7	1·8	3	10000001000000001
8	15·0	3	00000000000010001
9	30·0	1	10000000010010001
10	1·3	3	00000000000000000
11	12·0	3	10000100000001001
12	12·0	2	10000100000000001
13	35·0	2	10000000000000101
14	1·3	3	10000000000000001
15	35·0	2	10001010101000111
16	1·3	3	10001000100000111
17	12·0	1	00000000000000000
18	42·0	2	10000100000000010
19	25·0	2	10100000100000111
20	12·0	2	00000000000000111
21	8·0	3	00000000000000000
22	21·0	1	00000000000000001
23	30·0	1	00000000000010100
24	25·0	1	00000000000010001
25	19·0	2	00000000000000000
26	35·0	2	00000000000000000
27	41·0	2	00000000000000001
28	21·0	1	00000000000000001
29	27·0	1	10001000000010100
30	28·0	1	00000000000010001
31	25·0	2	00000000000000001
32	11·0	3	00000000010010001
33	3·0	3	10001010000000011
34	0·1	4	00000000000000000
35	21·0	2	10000000000000111
36	21·0	2	00000000000000101
37	9·0	1	00000000000000001
38	29·0	1	00000000000000001
39	25·0	2	00000000000000001
40	37·0	2	00000000000000000
41	0·8	3	10000000000000001
42	29·0	1	00000000000000100
43	27·0	1	10101010100010001
44	18·0	1	00000000000010001
45	45·0	2	00000000000000001
46	0·3	3	00000000000000000
47	22·0	2	00000000000000001
48	0·1	4	00000000000000000
49	0·1	4	00000000000000000
50	0·1	4	00000000000000000
51	0·1	4	00000000000000000
52	0·1	4	00000000000000000
53	0·1	4	00000000000000000
54	0·1	4	00000000000000000
55	0·1	4	00000000000000000
56	45·0	2	00000000000000001
57	26·0	1	10000000000010001
58	35·0	2	00000000000100001
59	0·1	4	00000000000000000
60	19·0	2	00000000000000001
61	48·0	2	00000000000000000
62	0·5	3	00000000000000001
63	1·7	3	00000000000000001
64	21·0	2	00000000000000001
65	0·1	4	00000000000000000
66	0·1	4	00000000000000000
67	35·0	1	00000000000000001
68	0·1	4	00000000000000000

Table 1. Continued

Burial	Age	Sex	Artefacts ABCDEFGHIJKLMNOPQ
69	0·1	4	00000000000000000
70	0·1	4	00000001000000000
71	0·1	4	00000000000000000
72	32·0	1	10000000000001101
73	25·0	2	11000000000000001
74	39·0	1	00000000000000001
75	0·1	4	10000000000000001
76	33·0	1	00000000000000001
77	26·0	2	00000000000000001
78	0·1	4	00000000000000000
79	47·0	2	00000000000000001
80	0·1	4	00000000000000000
81	0·1	4	00000000000000000
82	0·5	3	00000000000000110
83	30·0	2	00000000000000100
84	0·1	4	00000000000000000
85	0·1	4	00000000000000000
86	25·0	1	00000000000000001
87	24·0	2	10000000000000000
88	0·8	3	11000001000000001
89	0·5	3	10000000000000001
90	27·0	1	11000000000000001
91	45·0	1	11000000000000101
92	18·0	1	00000000000000001
93	42·0	1	10000000000000001
94	31·0	2	00100000001000100
95	0·1	4	00000000000000000
96	4·0	3	00000000000000100
97	0·5	3	00000000000000000
98	0·1	4	00000000000000000
99	0·6	3	10000000000000001
100	29·0	1	10000000000000000
101	1·5	3	11100000000000001
102	35·0	2	10000010000100001
103	26·0	1	11000000001000001
104	0·1	4	00000000000000000
105	0·3	3	11100000000000001
106	0·5	3	00000000000000000
107	40·0	2	00000000000000100
108	0·1	4	00000000000000000
109	31·0	2	10000000000000100
110	36·0	2	00000000000000101
111	0·1	4	00000000000000000
112	40·0	2	10000000000000001
113	46·0	2	11000000000000001
114	0·1	4	10000000000000000
115	38·0	1	00000000000000000
116	0·1	4	00000000000000000
117	16·0	1	01000000000000000
118	0·1	4	00000000000000000
119	0·1	4	00000000000000000
120	21·0	1	11000000000000001
121	1·3	3	01000000000000000
122	52·0	2	11000000000000000
123	2·0	3	10000000000000101
124	0·1	4	00000000000000000
125	0·1	4	10000000000000001
126	0·1	4	10000000000000000
127	0·1	4	00000000000000000
128	0·1	4	00000000000000000
129	27·0	1	01000000000000000
130	0·5	3	01000001000000001
131	25·0	1	00000000000000000
132	28·0	1	10110010000000100
133	0·4	3	01000001000000000
134	0·5	3	00000001000000000
135	0·3	3	00000000000000000
136	0·1	4	00000000000000000
137	5·0	3	00000000000000000
138	0·1	4	00000000000000000
139	0·1	4	00000000000000000
140	17·0	2	10000000000001000

Table 1. Continued

Burial	Age	Sex	Artefacts ABCDEFGHIJKLMNOPQ
141	0·1	4	00000000000000000
142	31·0	2	00000000000000000
143	0·1	4	10010000000000000
144	0·1	4	10000000000000000
145	8·0	3	00000000000000000
146	0·1	4	00000000000000000
147	19·0	1	00000000000000000
150	2·5	3	00000000000000000
151	0·1	4	00000000000000000
152	37·0	1	10010000000000000
153	0·1	4	00000000000000000
154	25·0	2	00000000000000000

Key to artefacts: A, disk beads; B, barrel beads; C, short barrel beads; D, funnel beads; E, I-shaped beads; F, H-shaped beads; G, animal teeth; H, fish bone bangles; I, shell disk bangles; J, bone fishhooks; K, polished stone implements; L, fish vertebra bangles; M, turtle carapace ornaments; N, stone adzehead; O, burnishing pebbles; P, clay anvils; Q, pottery vessels.

used in the context of testing for interactions between biological species on islands is proposed. Although the situations of artefacts in graves and species on islands appear at first sight to be quite different, the question of interest is the same from a statistical point of view. With artefacts in graves it becomes:

> Is there any evidence that certain artefacts tend to occur together, or do certain artefact combinations tend to be missing?

This can be compared with the ecologist's question:

> Is there any evidence that certain species tend to occur together, or are certain species combinations missing?

Equivalence is seen by equating the graves to islands and the artefacts to species.

In the ecological context there has been much debate about the assumptions which should be made concerning the number of species that can occur on an island and the number of times that a species can occur on different islands (Manly, 1991*a*, 234). One point of view is that, because some islands naturally have room for more species than other islands, the observed number of species on each island should be regarded as fixed. Similarly, it can be argued that some species are naturally more widespread than others and that therefore the observed number of occurrences of each species should be regarded as fixed. The question of interest can then be rephrased to become:

> Is there any evidence that the pattern of co-occurrences of species on islands appears to be non-random, subject to the constraint that the number of species on each island and the number of occurrences of each species must be equal to the totals observed in the data?

In the archaeological context this then becomes:

> Is there any evidence that the pattern of co-occurrences of artefacts in graves appears to be non-random, subject to the constraint that the number of artefacts in each grave and the number of occurrences of each artefact must be equal to the totals observed in the data?

In a recent paper, Manly (1995) proposed a new method for testing for non-randomness in the overall pattern of species co-occurrences, and also for detecting particular species with non-random patterns. This involves comparing certain statistics calculated from observed data with the values of the same statistics that are obtained by a stepwise process of randomly changing species occurrences whilst maintaining the observed total number of occurrences for each species and each island. The process is computer intensive, and is based on a theory of generalized Monte Carlo tests developed by Besag & Clifford (1989).

In the archaeological context the test involves the following steps, where the occurrence matrix is the array of zeros and ones that indicate the absences and presences of artefacts in graves (as in Table 1), e_{ij} denotes the expected number of times that artefacts i and j occur together in the same grave if artefacts were allocated independently of each other with the row and column totals of the occurrence matrix fixed at those obtained for the observed matrix, o_{ij} denotes the observed number of co-occurrences, and R is the number of artefacts:

(a) The overall deviation from expected numbers for all artefacts for the observed occurrence matrix is measured by the mean square of deviations

$$S = \sum_{i=1}^{R} \sum_{j=1}^{R} (o_{ij} - e_{ij})^2 / R^2, \tag{1}$$

(b) Noting that the statistic S can also be written as

$$S = \sum_{i=1}^{R} v_i / R,$$

where

$$v_i = \sum_{j=1}^{R} (o_{ij} - e_{ij})^2 / R, \tag{2}$$

v_i is used as a measure of the extent to which numbers of co-occurrences of other artefacts with artefact i differ from expectation.
(c) The observed value of S is tested to see whether it is significantly large by comparing it with values of the same statistic obtained by randomly changing the occurrence matrix without changing the row and column totals.
(d) The observed value of v_i is tested to see whether it is significantly large by comparing it with values of the same statistic obtained by randomly changing the occurrence matrix as in (c). To allow for multiple

Table 2. The statistics v_1 *to* v_{17} *for testing whether individual artefacts seem to have a non-random distribution in burials, with percentage* P-*values (the percentage of times that the* v_i *value was equalled or exceeded with randomly changed occurrence matrices)*

i	v_i	P (%)	i	v_i	P (%)	i	v_i	P (%)	i	v_i	P (%)
1	2·0	24·2	2	2·4	1·7	3	0·6	45·6	4	0·6	8·1
5	1·7	0·2*	6	0·6	33·0	7	1·4	0·8	8	1·0	8·7
9	1·9	0·3*	10	0·3	28·2	11	0·2	73·9	12	0·1	79·7
13	1·1	15·4	14	0·2	74·5	15	5·0	0·1*	16	2·8	0·1*
17	2·7	6·6									

*Significantly large at the 5% level after allowing for multiple testing.

testing, v_i is only declared to be significantly large at the $100\alpha\%$ level if the probability of a value as large as that observed is α/R, or less. According to the Bonferroni inequality the probability of declaring any of the v_i values significant in error is then α or less (Alt, 1982).

Because $o_{ii}=e_{ii}$ (every artefact always occurs with itself) it matters little whether or not cases with $i=j$ are included or excluded from the sums in equations (1) and (2). For simplicity of expression they are included here.

The test was carried out on the data in Table 1 using 25 replications of a series of 10,000 random changes to the observed occurrence matrix, as discussed by Manly (1995). The statistic S was found to be significantly large at the 0·05% level, which gives extremely strong evidence that the artefact distribution is not random. The v_1 to v_{17} values for the individual artefacts and their significance levels (the percentage of values as large or larger than that observed for randomly changed occurrence matrices) are shown in Table 2. If these values are required to be significantly large at the (5/17)%=0·3% level before they are considered to give evidence of non-randomness then the probability of declaring anything significant by chance alone is 0·05, or less. On this basis, the distributions for I-shaped beads, shell disk bangles, burnishing pebbles and clay anvils show evidence of non-randomness.

A comparison between observed and expected numbers of co-occurrences indicates that the nature of the apparent non-random distribution of artefacts is as follows.

(1) There are five burials containing I-shaped beads, and with a random distribution these are expected to occur with other artefacts about 15 times in total. However, in the actual burials they occur with 25 other artefacts. In particular, there are more than the expected number of co-occurrences with disk beads, animal teeth, shell disk bangles and clay anvils.
(2) There are six burials containing shell disk bangles, and with a random distribution these are expected to occur with other artefacts about 18 times in total. However, in the actual burials they occur with 29 other artefacts. In particular, there are more than the expected number of co-occurrences with I-shaped beads and clay anvils.
(3) There are 24 burials containing burnishing pebbles, and with a random distribution these are expected to occur with other artefacts about 58 times in total. However, in the actual burials there are only 52 co-occurrences. In particular, there are fewer than expected co-occurrences with barrel beads and pottery vessels. However there are more than the expected number of co-occurrences with clay anvils.
(4) There are 10 burials containing clay anvils, and with a random distribution these are expected to occur with other artefacts about 28 times in total. However, in the actual burials they occur with 33 other artefacts. In particular, there are more than the expected number of co-occurrences with shell disk bangles and burnishing pebbles.

These patterns are all archaeologically interesting. The burials have been divided into seven mortuary phases from MP1 (*c*. 2000 BC) to MP7 (*c*. 1500 BC) and all five of those with I-shaped beads are in MP4 and MP5. These five burials also have disk beads, three of the five occurrences of animal teeth, three of the six occurrences of shell disk bangles, and three of the 10 clay anvils. Thus the patterns (1), (2) and (4) are partly reflecting time changes in distributions.

Clay anvils are still used in Thailand for shaping clay into pots, and burnishing pebbles are still used for imparting a sheen to the clay. The patterns (3) and (4) therefore seem to be related to pottery making, with eight of the 10 burials with clay anvils also containing burnishing pebbles.

Displaying Data to Emphasize Similar Burials and Artefacts

Methods for studying the relationship between different burials and between different artefacts are considered in the following two sections. These are valuable, but it is also informative simply to display the occurrence matrix with the burials and artefacts in orders that are chosen to emphasize similarities and differences. The problem of how to do this is an old one that has been of interest to plant ecologists in particular for many years, with early solutions proposed by Braun-Blanquet (1932) and Beum & Brundage (1950). In archaeology the ordering process is called seriation, with a number of possible approaches being discussed in the proceedings edited by Hodson *et al.* (1971), or more recently by Baxter (1994).

Here only the method of Manly (1991*b*) will be considered. This first orders the burials and then the artefacts, in such a way as to maximize the correlation between the distance apart in an ordering (1, 2, 3, etc.) and the distance between the entities being considered. It has the advantage of being more direct and easier to understand than other approaches based on multivariate ordination techniques.

To make the procedure clearer, consider the ordering of the burials. The difference between the *i*th and *j*th of these with regard to artefacts can be measured in many different ways, with a simple approach being to use the number of artefacts that are present in only one of the two burials. For example, using this measure the difference between burial 1 and burial 2 is $d_{12}=3$ because burial 1 contains three types of artefact that are not in burial 2 but the only artefact present in burial 2 is also in burial 1 (Table 1). The correlation is maximized by a process of systematically swapping the positions of pairs of burials in a list whenever this increases the correlation between $|i-j|$ and d_{ij}. The process continues until the correlation is not increased by swapping any further pairs.

The ordering of artefacts proceeds using a similar algorithm. The difference between two types of artefact in terms of where they occur is measured by the number of burials that contain one of the two types but not the other. The correlation between this difference and the distance apart on a list of all artefacts is then maximized by the swapping process.

Because there are many burials with identical artefact contents and, in particular, 59 burials with no artefacts, the ordering of burials was carried out using only the 46 unique compositions observed. Multiple burials with the same contents were then placed one after another for a full listing of all burials. This modification to the ordering procedure was not necessary with the artefacts because they all displayed different distributions over the 153 burials.

The ordering of burials and artefacts obtained after carrying out the process of maximizing correlations is shown in Table 3. The first burial on the list is number 15, on the top left-hand side, which contains burnishing pebbles, a clay anvil, a shell disk bangle, I-shaped beads, animal teeth, polished stone implements, disk beads, and pottery vessels. This is the burial with the greatest number of different artefacts, and it is followed by a group of other graves with similar compositions. This group contains many of the burnishing pebbles, the clay anvils, the shell disk bangles and the I-shaped beads. It is, therefore, the association between these artefacts in this group of graves that is reflected in the non-random distributions noted in (1) to (4) of the previous section.

Burials with no artefacts occur in the middle of the listing, and at the other end of the list is burial 132 which contains burnishing pebbles, an animal tooth, funnel beads, short barrel beads and disk beads, preceded by a group of burials that is characterized by having two or three artefacts but few burnishing pebbles, no clay anvils, no shell disk bangles, and no I-shaped beads. The general pattern is, therefore, of burials with reasonably rich but different artefact collections at each end of the ordering, with empty graves between them.

Examining Relationships Between Burials

One approach that can be considered to examine the relationship between burials in terms of their artefact contents is ordination, where this involves constructing a small number of indices that summarize the presences and absences of the 17 artefacts to some extent. The hope is then that relationships will become clear when the burials are plotted against the indices.

There are many different ordination methods in use. The only one considered here is principal components analysis applied directly to the covariance matrix for the presence and absence data (Manly, 1994: chapter 6). In effect this means that the ordination axes obtained attempt to display the relationship between the burials as closely as possible, when the measure used to express the difference between two burials *i* and *j* is

$$D_{ij}=\sqrt{\{(\mathrm{x}_{i1}-x_{j1})^2+(x_{i2}-x_{j2})^2+\cdots+(x_{i17}-x_{j17})^2\}}, \quad (3)$$

where x_{ik} is 1 when burial *i* contains artefact type *k*, or is otherwise 0. The computer program MVSP (Kovach, 1991) was used for calculations.

There has been much discussion in the literature on whether it is appropriate to use joint absences in distance measures used for ordination. In the mortuary context, it must be decided whether the absence of an artefact from two burials should have the same effect as the presence of the artefact in both. This is the case with the distance measure of equation (3), which seems appropriate in this application.

The relative importance of different principal components ordination axes is indicated by the percentage of the variation in the presence and absence data that they account for. From this point of view, the results are not particularly good with the example data, with the first ten axes accounting for between 2·2% and 31·5%, respectively, of the variation. In particular, the first two components only account for 47·3% of the original variation, and the first three components only account for 60·4% of the original variation. Nevertheless, using the first two principal components highlights some interesting relationships between the burials (Figure 1).

Table 3. Occurrence matrix with rows and columns reordered to maximize the similarity between close rows and close columns. The key for artefacts A to Q is at the foot of Table 1

Burial	Artefacts OPIEGKDLJNCFHMBAQ
15	11111100000000011
43	00111000001001011
16	11110000000000011
19	11100000001000011
33	01011000000000011
1	11100000000000001
29	10010000000001010
4	11000000000000000
82	11000000000000000
20	11000000000000001
35	11000000000000011
18	01000000000100010
3	00100000000100011
6	10000000000100010
23	10000000000001000
72	10000000010000011
42	10000000000000000
83	10000000000000000
96	10000000000000000
107	10000000000000000
109	10000000000000010
13	10000000000000011
123	10000000000000011
36	10000000000000001
110	10000000000000001
91	10000000000000111
11	00000000010100011
12	00000000000100011
14	00000000000000011
41	00000000000000011
75	00000000000000011
89	00000000000000011
93	00000000000000011
99	00000000000000011
112	00000000000000011
125	00000000000000011
57	00000000000001011
87	00000000000000010
100	00000000000000010
114	00000000000000010
126	00000000000000010
144	00000000000000010
140	00000000010000010
2	00000000000000001
22	00000000000000001
27	00000000000000001
28	00000000000000001
31	00000000000000001
37	00000000000000001
38	00000000000000001
39	00000000000000001
45	00000000000000001
47	00000000000000001
56	00000000000000001
60	00000000000000001
62	00000000000000001
63	00000000000000001
64	00000000000000001
67	00000000000000001
74	00000000000000001
76	00000000000000001
77	00000000000000001
79	00000000000000001
86	00000000000000001
92	00000000000000001
5a	00000000000000000
5b	00000000000000000
10	00000000000000000
17	00000000000000000

Table 3. Continued

Burial	Artefacts OPIEGKDLJNCFHMBAQ
21	00000000000000000
25	00000000000000000
26	00000000000000000
34	00000000000000000
40	00000000000000000
46	00000000000000000
48	00000000000000000
49	00000000000000000
50	00000000000000000
51	00000000000000000
52	00000000000000000
53	00000000000000000
54	00000000000000000
55	00000000000000000
59	00000000000000000
61	00000000000000000
65	00000000000000000
66	00000000000000000
68	00000000000000000
69	00000000000000000
71	00000000000000000
78	00000000000000000
80	00000000000000000
81	00000000000000000
84	00000000000000000
85	00000000000000000
95	00000000000000000
97	00000000000000000
98	00000000000000000
104	00000000000000000
106	00000000000000000
108	00000000000000000
111	00000000000000000
115	00000000000000000
116	00000000000000000
118	00000000000000000
119	00000000000000000
124	00000000000000000
127	00000000000000000
128	00000000000000000
131	00000000000000000
135	00000000000000000
136	00000000000000000
137	00000000000000000
138	00000000000000000
139	00000000000000000
141	00000000000000000
142	00000000000000000
145	00000000000000000
146	00000000000000000
147	00000000000000000
150	00000000000000000
151	00000000000000000
153	00000000000000000
154	00000000000000000
8	00000000000001001
24	00000000000001001
30	00000000000001001
44	00000000000001001
7	00000000000010011
143	00000010000000010
152	00000010000000010
73	00000000000000111
90	00000000000000111
113	00000000000000111
120	00000000000000111
9	00000000100001011
58	00000001000000001
102	00001001000000011
122	00000000000000110
103	00000100000000111

Table 3. Continued

Burial	Artefacts OPIEGKDLJNCFHMBAQ
101	00000000001000111
105	00000000001000111
88	00000000000010111
117	00000000000000100
121	00000000000000100
129	00000000000000100
70	00000000000010000
134	00000000000010000
130	00000000000010101
32	00000000100001001
133	00000000000010100
94	10000100001000000
132	10001010001000010

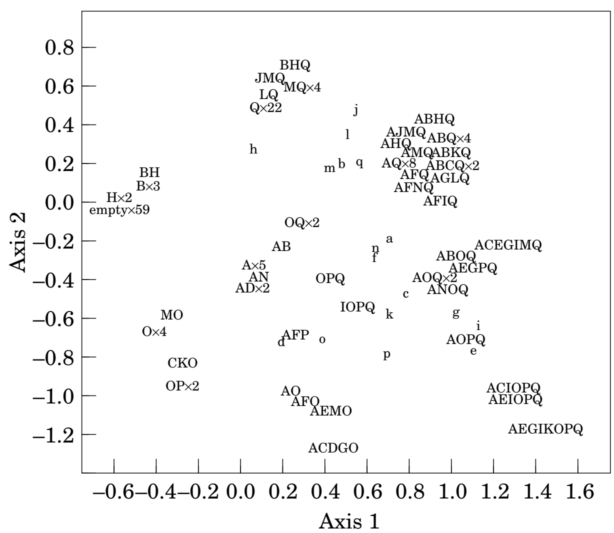

Figure 1. Two dimensional principal component ordination of burials, with artefact contents plotted.

In the figure the composition in terms of the artefacts A to Q is plotted against the two ordination axes for each burial, with multiple burials indicated. For example, the 59 burials with no artefacts are indicated by "empty × 59" at about − 0·6 on axis 1 and 0·0 on axis 2. Similarly, the single burial containing artefacts "AEGIKOPQ" is plotted against about 1·5 for axis 1 and − 1·2 for axis 2. In addition, the lower case letters that are plotted show the averages of the two axes for the burials containing a particular artefact. For example, "h" is plotted at about 0·0 on axis 1 and 0·3 on axis 2 because this is the centroid for the burials containing artefact H (fish bone bangles).

The non-random patterns detected by the randomization test described above show up in Figure 1 as a tendency for burials with particular combinations of artefacts occurring close together. Thus the association between I-shaped beads, shell disk bangles, animal teeth and clay anvils shows up by most of the burials containing these items being on the right-hand side of the plot. Similarly, the lack of burials containing both burnishing pebbles and disk beads or both burnishing pebbles and pottery vessels shows up by all of the burials containing burnishing pebbles appearing in the bottom part, while disk beads and pottery vessels appear in other parts of the plot.

Based on the distribution of artefacts in the burials, an obvious interpretation of axis 1 is that high values occur with the presence of disk beads and pottery vessels, while for axis 2 high values occur with the absence of burnishing pebbles.

Cluster analysis is an alternative to ordination that seems potentially useful for studying the relationship between burials. Two general approaches are then available for use. Either a hierarchic method can be used to produce a dendrogram showing the relationship between burials, or a partitioning method can be used to divide the burials into a fixed number of groups. Because there is no reason to believe that there are distinct clusters of burials, the hierarchic approach seems most sensible, and it is the only one considered here.

The computer program MVSP (Kovach, 1991) was used to produce dendrograms by three agglomerative methods: (a) nearest neighbour linkage, where two groups of burials join providing that one burial in one group is sufficiently similar to one burial in the other group; (b) furthest neighbour linkage, where two groups can join only if all burials in one group are sufficiently similar to all burials in the other group; and (c) the unweighted pair methods, where two groups join if the average pairwise difference between the burials in one group and the burials in the other group is sufficiently small. The "distance" between burials was in all cases measured using equation (3).

None of the dendrograms produced was really satisfactory. With nearest neighbour linkage, there is very little separation of burials, with 36 different artefact compositions being placed into a single large group (Figure 2(a)). However, with furthest neighbour and unweighted pairs linkage Figures 2(b) & 2(c) show that the 59 empty burials were arbitrarily joined with the three burials containing artefact B at the first level of merging, although the empty burials could just as well have been joined with any of the other burials containing a single artefact. As a result, with these two dendrograms the empty burials appear to be quite different from some similar burials. For example the empty burials and the burials containing only pottery vessels appear quite different on the dendrograms, although they only differ by one artefact.

This example suggests that cluster analysis should be used with caution: it does not seem to be as useful as ordination, and will not be considered further.

Examining Relationships Between Artefacts

Although some relationships between artefacts in terms of their distributions in burials have already

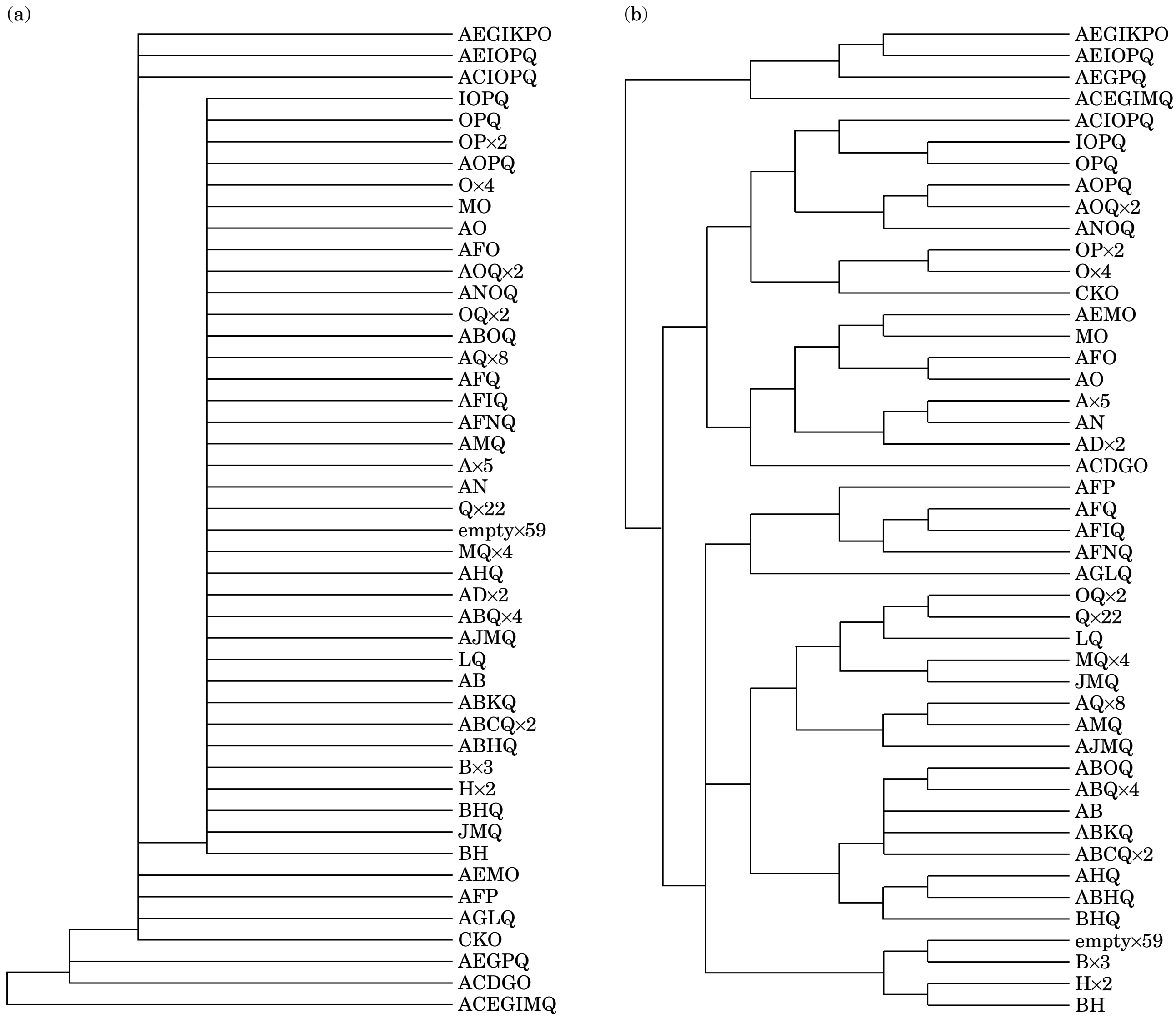

Figure 2. Cluster analysis of burials using three hierarchic agglomerative methods. (a) Nearest neighbour method, (b) furthest neighbour method, (c) Unweighted pairs method.

become apparent, it is still interesting to devote some attention more specifically to these relationships. The two obvious techniques that can be used are ordination and cluster analysis, as was the case when considering the relationships between burials.

To begin with, a principal components ordination was carried out using the computer program MVSP (Kovach, 1991), with the 17 types of artefact as the objects of interest and treating the 153 burials as if they were variables measured on the artefacts. The analysis was based on the covariance matrix of these 153 variables. The first ten principal components accounted for between 2·0% and 39·2% of the total variation in the data, with the first two components between them accounting for 52·6% and the first three components between them accounting for 65·1%.

Figure 3 shows the artefacts plotted against their scores on the first two principal components, with their values for the third principal component shown in parenthesis. Axis 1 is mainly a measure of the frequency with which the artefacts occur, ranging from a low of about -2 for stone adzeheads with three occurrences to a high of about 6 for pottery vessels, with 66 occurrences. Axis 2 is a contrast between pottery vessels and disk beads, and burnishing pebbles. A comparison with Figure 1 shows that in fact the two axes are essentially the same as those obtained from the ordination of sites.

Burial Contents Related to Other Variables

Consideration will now be given to the question of how the contents of burials are related to age and sex, noting that these characteristics are related because the age ranges of males and females overlap the ages of

(c)

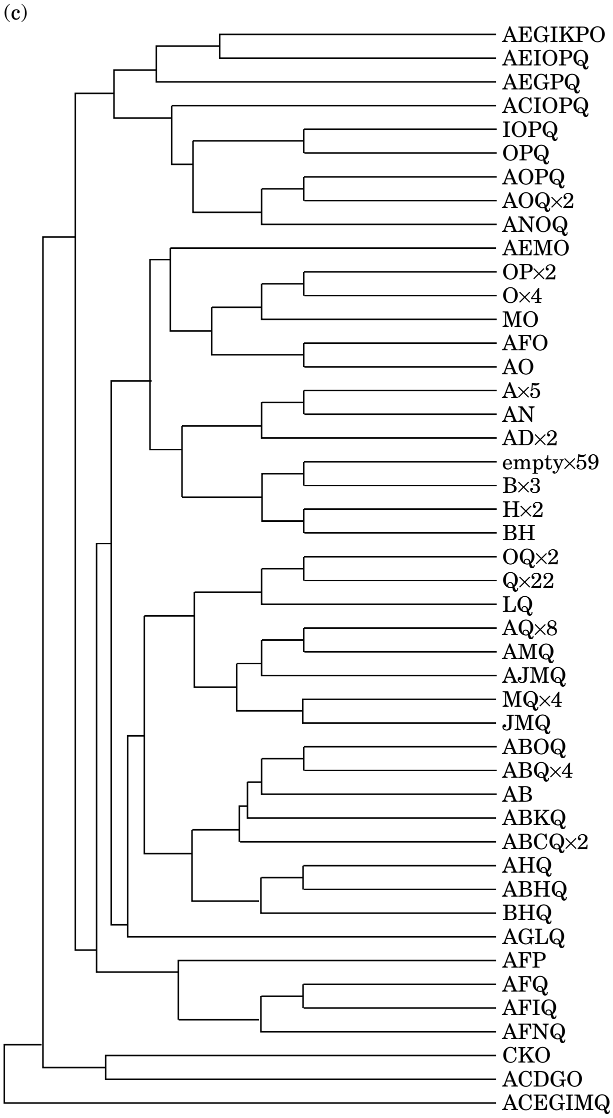

Figure 2(c).

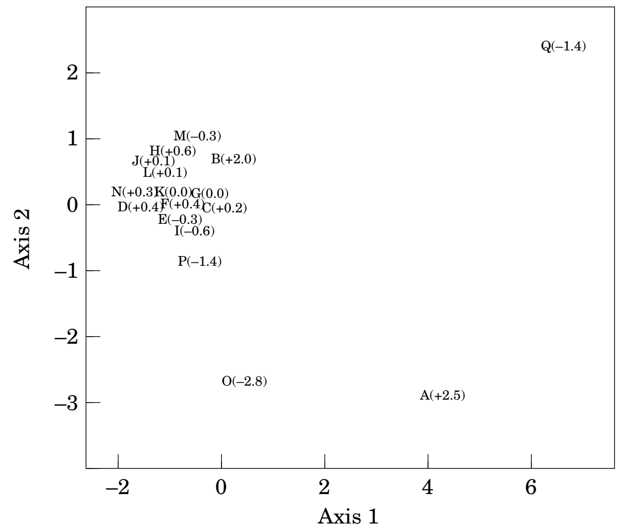

Figure 3. Two dimensional principal component ordination of artefacts. The artefact codes are defined at the foot of Table 1.

unsexed children, and the infants (many of which were probably stillborn) have all been assigned an age of 0·1 of a year.

Two approaches have been used to examine relationships. First, Mantel randomization tests (Manly, 1994: chapter 5) have been used to see whether differences between the contents of burials are related significantly to differences between sex and age. Second, logistic regression (Manly, 1994: chapter 8) has been used to see whether the probability of a burial containing a particular type of artefact is significantly related to one or both of the same two factors. Mantel randomization tests have previously been used by Sokal *et al.* (1987) to study hypotheses related to mortuary data from mediaeval Hungarian cemeteries. Logistic regression can be thought of as an extension to the commonly used chi-square test for a relationship between two classifications with count data.

For the Mantel tests, the difference between the contents of two burials has been measured using equation (3), the difference in the type of body has been set at 0 for the same type, and 1 for a different type, and the difference in age has been set at the absolute difference in years. The tests were carried out using the computer program RT (Manly, 1993) which calculates a regression equation to relate a single dependent distance variable (in this case the difference between burial contents of artefacts) to one or more explanatory distances (in this case type of body differences and age of body differences). The significance of the regression coefficients is then assessed by comparing them with null hypothesis distributions obtained by randomly reallocating the artefact contents to the burials.

The justification for the null hypothesis used is the idea that if the artefact contents of a burial are unrelated to the type of body and its age then the observed allocation of artefacts to burials was equally likely to be any one of the possible allocations that can be obtained randomly. On the other hand, if the artefact contents of burials are related to the type of the body then it can be expected that burials with bodies of the same type will tend to have smaller artefact difference between them than burials with bodies of a different type. Similarly, if the artefact contents of a burial are related to the age of the body then small age differences should be associated with small artefact differences. The hope is that these effects will be detected with significant regression coefficients.

Several Mantel tests were run with 1000 randomizations each in an attempt to clarify the relationships between artefact contents and both sex and age. Particular examples of these are as follows.

(a) Only male burials were considered, and artefact differences were related to differences in age. The

regression was not significant at the 5% level ($P=0{\cdot}113$).
(b) Only female burials were considered, and artefact differences were related to differences in age. The regression was not significant at the 5% level ($P=0{\cdot}575$).
(c) Only child burials were considered, and artefact differences were related to differences in age. The regression was not significant at the 5% level ($P=0{\cdot}179$).
(d) Males, females and children were considered, and artefact differences were related to differences between sex and age. Neither variable accounted for a significant amount of the variation in artefact differences.
(e) All individuals were considered with the exception of 5b (an infant which was in the same location as 5a), and artefact differences were related to differences between sex and age. It was found that both of the explanatory variables accounted for a significant part of the variation in artefact differences, and that the regression equation including both two explanatory variables was significantly better than either of the equations with one of the variables only. Essentially the same result was also found when males, females and children were considered to be of the same type.

From these tests, significant relationships between artefact differences and sex and age differences are only found when the 46 infant burials are included in the analysis. That is to say, the tests are indicating a difference between the artefacts found with infants and the artefacts found with other types of body, but no other effects. Inspection of the data easily explains why this is the case: the 46 infant burials are mostly devoid of artefacts, and as a group contain far fewer than the male, female, and child burials.

One of the advantages of Mantel tests is that they test for overall patterns of differences between artefacts from males, females and different ages. The price paid is a lack of ability to detect patterns with single artefacts. However, these patterns can be detected by fitting logistic regression models to the results for each of the artefacts.

To clarify how this can be done, consider the category of disk beads. These occurred in 47 of the burials in a way that can be conveniently summarized as shown in Table 4. It can be seen from this table that there was a lack of this artefact in burials of males under 21 and infants. The significance of these apparent effects can be assessed by considering the fit to the data of several logistic models. These were fitted using the computer program GLIM (Payne, 1987), which measures the goodness of fit using a statistic called the "deviance" with an associated degrees of freedom (*df*). A poor fit is indicated by the deviance being significantly large in comparison with the chi-square distribution. Also, the reduction in deviance in moving from one model to another model that is more complicated can be tested against the chi-square distribution to see whether the more complicated model fits the data significantly better than the simpler model.

Table 4. Distribution of disk beads over burials with bodies of different types and different ages

Type of body	Age of body (years)	Number of Burials	Number of Disk beads	Proportion with disk beads
Male	Under 21	9	1	0·10
	21–30	16	8	0·50
	Over 31	8	4	0·50
Female	Under 21	8	3	0·38
	21–30	10	3	0·30
	Over 31	20	8	0·40
Children	Under 21	35	14	0·40
Infants	0·1	46	6	0·13
		152	46	0·30

The models considered for the probability of disk beads being present in a burial are as follows.

Model 0: constant probability of the artefact being present

According to this "null" model, the probability of disk beads appearing in a burial was

$$P=\exp(\alpha)/\{1+\exp(\alpha)\},$$

i.e. the probability was the same for all burials. This model fits poorly (chi-square$=16{\cdot}01$, 7 *df*, $P<0{\cdot}05$).

Model 1: probability of presence varies with the type of body

In this case it is assumed that

$$P=\exp(\alpha+T_i)/\{1+\exp(\alpha+T_i)\},$$

where T_i ($i=1, 2, 3, 4$) varies with the type of body (male, female, child, or infant). This model fits the data well (chi-square$=5{\cdot}00$, 4 *df*, $P>0{\cdot}1$), and is a significant improvement of Model 0 (chi-square$=11{\cdot}01$, 3 *df*, $P<0{\cdot}05$).

Model 2: probability of presence varies with the type and age of body

This model assumes that the age effect is the same for males and females, with

$$P=\exp(\alpha+T_i+A_j)/\{1+\exp(\alpha+T_i+A_j)\},$$

where A_j ($j=1, 2, 3, 4$) varies with the age group (infants, under 21, 21–30, or over 30). This model fits the data well (chi-square$=2{\cdot}82$, 2 *df*, $P>0{\cdot}1$), but is not a significant improvement on Model 1 (chi-square$=2{\cdot}18$, 2 *df*, $P>0{\cdot}1$).

Model 3: effect of age varies with the type of the body

In this case

$$P=\exp(\alpha+T_i+A_j+TA_{ij})/\{1+\exp(\alpha+T_i+A_j+TA_{ij})\},$$

where TA_{ij} are parameters that are intended to allow the effect of age to vary with the type of body.

Table 5. Proportions of burials containing different types of artefact for males and females in three age classes, children and infants. Significant relationships between the proportions and the type of body and/or the age of the body from logistic regression are indicated in the last two columns

		Male			Female						Significant relationships	
		<21	21–30	31+	<21	21–30	31+	Children	Infants	Total occurrences	Type	Age
	Number of burials	9	16	8	8	10	20	35	46			
A	Disk beads	0·11	0·50	0·50	0·38	0·30	0·40	0·40	0·13	47	*	
B	Barrel beads	0·22	0·19	0·13	0·00	0·10	0·10	0·17	0·00	15	**	
C	Short barrel beads	0·00	0·13	0·00	0·00	0·10	0·05	0·06	0·00	6		
D	Funnel beads	0·00	0·06	0·13	0·00	0·00	0·00	0·00	0·02	3		
E	I-shaped beads	0·00	0·13	0·00	0·00	0·00	0·05	0·06	0·00	5		
F	H-shaped beads	0·00	0·00	0·00	0·13	0·00	0·05	0·09	0·00	5	*	
G	Animal teeth	0·00	0·13	0·00	0·00	0·00	0·10	0·03	0·00	5		
H	Fish bone bangles	0·00	0·00	0·00	0·00	0·00	0·00	0·14	0·02	6	**	
I	Shell disk bangles	0·00	0·06	0·00	0·00	0·10	0·05	0·09	0·00	6		
J	Bone fishhooks	0·00	0·06	0·00	0·00	0·00	0·00	0·03	0·00	2		
K	Polished stone implements	0·00	0·06	0·00	0·00	0·00	0·10	0·00	0·00	3		
L	Fish vertebra bangles	0·00	0·00	0·00	0·00	0·00	0·10	0·00	0·00	2		
M	Turtle carapace ornaments	0·11	0·44	0·00	0·00	0·00	0·00	0·06	0·00	10	***	*
N	Stone adzehead	0·00	0·00	0·13	0·13	0·00	0·00	0·03	0·00	3		
O	Burnishing pebbles	0·00	0·25	0·25	0·38	0·30	0·30	0·17	0·00	24	***	
P	Clay anvils	0·00	0·00	0·00	0·25	0·20	0·10	0·11	0·00	10	**	
Q	Pottery vessels	0·67	0·56	0·75	0·75	0·60	0·55	0·57	0·04	66	***	

*: significant at the 5% level; **: significant at the 1% level; ***: significant at the 0·1% level.

Because more than one age group is present only with male and female bodies the only real difference between this model and Model 2 is that the effect of age is allowed to be different for males and females. This model fits the data perfectly (chi-square=0·00, 0 *df*), but is not a significant improvement on Model 2 (chi-square=2·18, 2 *df*, $P>0·1$).

From this analysis, it appears that the probability of disk beads being present varies significantly with the type of body, but not otherwise with the age of the body. Therefore, the lack of disk beads with the infant burials appears to be meaningful, but the small number with male burials under 21 years could be due to chance.

The results of this analysis are summarized in Table 5 for all artefacts. Of course, some of the artefacts occurred so seldom that it is not possible to obtain a significant result. However, Table 5 does suggest the following.

(a) As already noted, disk beads only occur rarely with infants, but are otherwise quite common.
(b) Barrel beads are lacking with females and infants.
(c) H-shaped beads occur with females and children only.
(d) Fish bone bangles occur with children and infants only.
(e) Turtle carapace ornaments occur only with children and men under 31.
(f) Burnishing pebbles occur mainly with females, children, and older men.
(g) Clay anvils occur with females and children only.
(h) Pottery vessels do not occur with infants.

It can be argued that an adjustment for multiple testing should be used with the tests based on the logistic model, in the same way as for the randomization tests for non-random distributions of artefacts that was considered in the second section of this paper. However, the situation is different because a Mantel test has already provided strong evidence of artefact differences at least between infant and other types of burials. The tests on individual artefacts are therefore more for the sake of deciding where differences occur than for deciding whether the differences exist. For this purpose tests without an adjustment for multiple testing seem appropriate.

Further Remarks and Conclusions

It is not claimed that the statistical methods described in this paper are the only ones that could have been used. With ordination and cluster analysis in particular, there are many other methods and options. The hope must be that alternative methods would lead to the same conclusions.

With regard to ordination, two obvious alternative methods are non-metric scaling and correspondence analysis (Manly, 1994: chapter 12). Without going into details, it can be mentioned that non-metric scaling using Euclidean distances gives a two-dimensional solution for the ordination of burials that is rather similar to the one obtained by principal components analysis as shown in Figure 1. However, a two-dimensional non-metric scaling ordination of artefacts is rather unsatisfactory because most of the artefacts are found to be almost identical. Correspondence analysis is currently a popular method of ordination but this cannot be applied immediately to the example data because there is a requirement for all the rows and columns in the data matrix to be positive but this is not the case where there are no grave goods. It seems that this problem can be overcome by assigning values of 0 to the empty burials and then omitting them from the analysis. However, this approach was not considered because it was simpler to use a method for which empty burials cause no problems.

One potentially important aspect of the analysis of mortuary data that has not been considered here is the extent to which artefact distributions vary in space. This is an area where the Mantel randomization test can be very useful, as demonstrated by Sokal *et al.* (1987). The application of this test with data on the presences and absences of artefacts and the positions of burials will be the subject of another paper.

Finally, it is useful briefly to review the conclusions that have been reached with regard to the example set of data from Khok Phanom Di. These are as follows.

(a) There is extremely strong evidence that artefact co-occurrences are not the result of a random allocation of artefacts to graves, given the total number of occurrences of each artefact and the total number of artefacts in each grave. Four artefacts in particular (I-shaped beads, shell disk bangles, burnishing pebbles and clay anvils) show significantly non-random combinations with other artefacts.
(b) Burials can be characterized in a two-dimensional plot for which one axis largely relates to the presence or absence of both disk beads and pottery vessels, and the second axis relates to the presence and absence of burnishing pebbles.
(c) Artefacts can be characterized by a two-dimensional plot for which one axis relates to the total abundance and the second axis is a contrast between pottery vessels on the one hand, and disk beads and burnishing pebbles on the other hand.
(d) Burial contents vary significantly with the type of body (male, female, child or infant). The most obvious effect is that infant burials are lacking in artefacts, but other patterns are also present. However, there is little evidence of differences between artefact distributions related to burials of different ages within the male, female or child groups.

Acknowledgement

I am very grateful to C. F. W. Higham of the Department of Anthropology, University of Otago, for providing the data, commenting on earlier versions of this paper, and generally assisting me with matters of fact and interpretation.

References

Alt, F. B. (1982). Bonferroni inequalities and intervals. *Encyclopedia of Statistical Sciences* **1**, 294–300.

Baxter, M. J. (1994). *Exploratory Multivariate Analysis in Archaeology*. Edinburgh: Edinburgh University Press.

Bech, J. (1988). Correspondence analysis and pottery chronology: a case from the Late Roman Iron Age cemetry Slusegård, Bornholm. In (T. Madsen, Ed.) *Multivariate Archaeology: Numerical Approaches in Scandinavian Archaeology*. Aarus: Aarus University Press. pp. 29–35.

Besag, J. & Clifford, P. (1989). Generalized Monte Carlo significance tests. *Biometrika* **76**, 633–642.

Beum, C. O. & Brundage, E. G. (1950). A method for analysing the sociomatrix. *Sociometry* **13**, 141–145.

Braun-Blanquet, J. (1932). *Plant-Sociology: the Study of Plant Communities*. London: Hafner Press.

Chapman, R., Kinnes, I. & Randsborg, K., Eds. (1981). *The Archaeology of Death*. Cambridge: Cambridge University Press.

Doran, J. E. & Hodson, F. R. (1975). *Mathematics and Computers in Archaeology*. Edinburgh: Edinburgh University Press.

Higham, C. F. W. & Bannanurag, R. (1990). *The Excavation of Khok Phanom Di, a Prehistoric Site in Central Thailand. Volume 1: The Excavation, Chronology and Human Burials*. London: Society of Antiquaries.

Higham, C. F. W. & Bannanurag, R., Eds. (1992). *The Excavation of Khok Phanom Di, a Prehistoric Site in Central Thailand. Volume 2: The Biological Remains (Part I)*. London: Society of Antiquaries.

Higham, C. F. W. & Thosarat, R. (1994). *Khok Phanom Di: Prehistoric Adaption to the World's Richest Habitat*. Fort Worth: Harcourt Brace.

Hodson, F. R., Kendall, D. G. & Tautu, P., Eds. (1971). *Mathematics in the Archaeological and Historical Sciences*. Edinburgh: Edinburgh University Press.

Kovach, W. L. (1991). *Multivariate Statistical Package Plus, Version 2.1*. Anglesey, Wales: Kovach Statistical Services.

Manly, B. F. J. (1991*a*). *Randomization and Monte Carlo Methods in Biology*. London: Chapman and Hall.

Manly, B. F. J. (1991*b*). The statistical analysis of shell species counts. In (C. F. W. Higham & R. Bannanurag, Eds). *The Excavation of Khok Phanom Di, a Prehistoric Site in Central Thailand. Volume 2: The Biological Remains (Part 1)*, London: Society of Antiquaries, pp. 321–331.

Manly, B. F. J. (1993). *RT, a program for randomization testing*. Technical Report, Centre for Applications of Statistics and Mathematics, University of Otago, New Zealand.

Manly, B. F. J. (1994). *Multivariate Statistical Methods: a Primer*. 2nd Edn. London: Chapman and Hall.

Manly, B. F. J. (1995). A note on the analysis of species co-occurrences. *Ecology* **76,** 1109–1115.

Nielsen, K. H. (1988). Correspondence analysis applied to hoards and graves of the Germanic Iron Age. In (T. Madsen, Ed.) *Multivariate Archaeology: Numerical Approaches in Scandinavian Archaeology*. Aarus: Aarus University Press. pp. 37–54.

O'Shea, J. M. (1984). *Mortuary Variability: An Archaeological Investigation*. Orlando, FL: Academic Press.

Payne, C. D., Ed. (1987). *The GLIM System, Release 3·77*. Oxford: Numerical Algorithms Group.

Sokal, R. R., Lengyel, I. A., Derish, P. A., Wooton, M. C. & Oden, N. (1987). Spatial autocorrelation of ABO serotypes in medieval cemeteries as an indicator of ethnic and familial structure. *Journal of Archaeological Science* **14**, 615–633.