ARTICLES

CERAMIC STYLE CHANGE AND NEUTRAL EVOLUTION: A CASE STUDY FROM NEOLITHIC EUROPE

S. J. Shennan and J. R. Wilkinson

Following on the work of Dunnell, the evolutionary archaeology school has made a sharp distinction between functional and stylistic variation in archaeological artifacts. Variation is defined as functional if it is affected by selection processes and as stylistic if it is a result of processes of random drift. The argument has been further developed by Neiman (1995), who showed by simulation that processes of cultural mutation and drift could produce the kinds of "battleship curves" that generally characterize artifact-style frequency distributions through time, and also demonstrated that they could account for patterns of stylistic variation through time in Woodland-period ceramic assemblages from Illinois. In this paper we present a case study of change in the decoration of pottery from early Neolithic Central Europe. We show that the actual diachronic frequency distributions and those expected under the neutral model do not coincide and conclude that in this case the neutral model does not provide an adequate description of change in ceramic decoration. A model involving selection, in the form of a bias in favor of novelty in the later phases of the period studied, seems likely to be more appropriate, and we note the social interpretation of the original investigator of the data. In conclusion, it is suggested that neutral models provide an important heuristic tool but that there is not a radical break between functional and stylistic variation.

Siguiendo a Dunnell, la escuela de 'arqueología evolucionista' ha profesado una clara distinción entre la variación funcional y la variación estilística de los artefactos arqueológicos. Se puede definir variación como funcional si ésta es afectada por procesos de selección y como estilística si es el resultado de procesos de deriva aleatoria. Este argumento ha sido desarrollado en mayor detalle por Neiman (1995), quien demostró por medio de estudios de simulación que los procesos de mutación y deriva producen los tipos de curvas en forma de "barcos de batalla" que generalmente caracterizan la distribución de estilos del artefacto y quién además demostró que estos procesos explican los patrones de variación estilística de los conjuntos cerámicos del período Woodland en Illinois. En este ensayo nosotros presentamos un ejemplo del cambio de la decoración en la cerámica del Neolítico temprano de Europa Central. Demostramos que las distribuciones de frecuencias actuales diacrónicas así como las esperadas en el modelo neutral sencillamente no proveen una explicacación adecuada de los cambios de decoración en la cerámica. Antes bien, proponemos que es más probable que la explicación resida en un modelo de selección, el cual favorece innovación hacia las fases finales del período bajo consideración tomando además en cuenta la interpretación social que el investigador original extrajo de los datos. En conclusión sugerimos que los modelos explicativos neutros nos proporcionan una importante herramienta heurística pero que, a su vez, hay una separación radical entre la variación funcional y la estilística.

In the last few years the application of Darwinian ideas to archaeology, and to anthropology more generally, has grown apace (e.g., Barton and Clark 1997; Maschner 1996; Smith and Winterhalder 1992; Teltser 1995), and divergent opinions abound about the nature of the ideas and the way in which they should be applied to the study of human behavior and its products. One of the most influential Darwinian approaches has come to be known as evolutionary archaeology. This perspective sees cultural phenomena as inherited lineages that are directly affected by such processes as natural selection and drift, so that it is possible to explain change in the archaeological record without involving behavioral reconstruction, which is regarded as "unscientific" (Lipo et al. 1997).

One of the main strengths of the evolutionary archaeology school has been its strong focus on the

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temporal patterning in the artifactual record recovered by archaeologists, and not least on explicating the role and significance of the culture-history perspective that dominated American archaeology in the first half of the twentieth century (e.g., Lyman et al. 1997). As far as *explaining* these culture-historical patterns is concerned, the evolutionary archaeology school has insisted on a strict dichotomy between the "style" and the "function" of artifacts (Dunnell 1980; Lipo et al. 1997; Neiman 1995). Variation is defined as functional if it may be accounted for in terms of selection and stylistic if it is not under selection (Lipo et al. 1997:304). In this sense stylistic variation is "neutral," affected only by variations in transmission processes (i.e., who interacts with and learns from whom) and rates of innovation (Kimura 1983).

A significant recent development in this context has been Neiman's (1995) simulation of artifact replication and innovation processes on the assumption that these are governed solely by the random processes involved in the neutral theory and the factors that affect these processes, such as effective population size. Neiman showed that such processes acting alone were capable of producing the kinds of diachronic patterns in type frequency observed by culture historians and that make it possible for seriation to work as an ordering procedure. He went on to show that patterns of within- and between-assemblage diversity in decoration in a diachronic series of Woodland-period ceramic assemblages could be accounted for in terms of drift and rates of inter-group transmission.

Given the importance of the theoretical distinction between functional and stylistic variation, it is of corresponding importance to be able to distinguish the two in practice. It has been suggested that one way of doing this is to look at changes in the frequency of attributes through time: stylistic features will increase and decrease stochastically in relative frequency while traits that are under selection will increase in frequency until they are fixed (O'Brien and Holland 1992; O'Brien and Lyman 2000). However, a trend to fixation is not the only possible outcome of selection processes, which can also lead to patterns of increasing and decreasing frequency—for example, in so-called Red Queen environments (and see below).

Another suggestion has been that seriation can be used to distinguish the two, because the unimodal pattern of a rise then a fall in the relative frequency of historical types arises from the stochastic character of neutral transmission (Lipo et al. 1997:310). Neiman's simulations have indeed shown that processes of drift can produce such patterns, but they have not shown that they are the only such mechanism, as he points out (1995:12). In the limit it seems reasonable to suppose that variation that is subject to strong selection will not conform to the unimodal historically significant pattern, but there is a spectrum of possibilities in between, where variation subject to a combination of drift and weak selection may well be amenable to seriation (see below). Since we do not know where the border lies we cannot use the method to make the required categorical distinction between the functional and the stylistic. Furthermore, there is considerable support from cross-cultural ethnographic studies for the view that there is a strong historical descent signal in variation that everyone would recognize as likely to be selected, such as subsistence and kinship patterns (Guglielmino et al. 1995; Mace and Pagel 1994).

In some cases, though, the distinction may be made simply on the basis of prior assumptions about what is likely to be functional and what is not. Thus, in a discussion of the features of house form which are likely to be stylistic (i.e., neutral), O'Brien and Lyman (2000:89–90) suggest that while the presence of a trait such as door mouldings might be functional, in the sense of representing an important display of wealth, the type of moulding used might well be unimportant and therefore subject only to neutral evolutionary processes.

It seems that the rationale for such assumptions is the idea that such variation has no cost, or rather that there is no cost difference in using one variant rather than another. While this may be true as far as the time/energy costs of the activity of producing the mouldings are concerned, there is no reason to believe that it will always be true of the anticipated *consequences* of using a particular variant. This may well affect the probability of that variant being taken preferentially as a model in processes of directly and indirectly biased cultural transmission (Boyd and Richerson 1985), associated, for example, with expressing group affiliation. Conversely, it has recently been suggested that the appearance and disappearance of pre-Upper Paleolithic blade technologies, preeminently functional one would have thought *a priori*, are to a considerable extent the result of drift processes (Bar-Yosef and Kuhn 1999). In these circumstances it seems to us unhelpful to use the terms "functional" and "stylistic" to distinguish variation under selection from that which is not, especially if evolutionary archaeology wishes to convince nonadherents in the archaeological community of its virtues. "Style" in particular has a much broader meaning in archaeology as a whole and is certainly not restricted to neutral variation. Indeed, much of the discussion in the literature of the last twenty years has been about the active role of style in society (see, e.g., Hegmon 1992).

In light of the shortcomings noted above in existing methods of distinguishing neutral variation from variation affected by other evolutionary forces, and what we see as the problematical nature of making an absolute distinction between the two, the object of this paper is to present a case study using high-resolution data to test the relevance of the neutral model to account for patterns of change in ceramic decoration. We use the methods developed by Neiman (1995) to provide a better means than those described above for distinguishing whether or not patterns of change fit a neutral model. We show that, in contrast to Neiman's Woodland example, in this instance the neutral model does not adequately describe the processes of change in the frequency of decorative attributes on pottery. We go on to explore reasons why this might be the case.

The Data

The data set published by Frirdich (1994) of the frequencies of decorative band-types from the Linearbandkeramik (LBK) Neolithic settlements of the Merzbachtal in western Germany provides the basis of our study. The settlements belong to the first farming culture in Central Europe and are characterized by long houses and pits scattered in groups of varying size over an area of about 3 km^2 (Figure 1). The number of houses in occupation varies through time, but altogether the settlement and ceramic sequence covers nearly five centuries, from ca. 5300 to 4850 cal B.C. The sites were almost completely excavated prior to their destruction by lignite mining. The ceramic vessels are broadly ovoid in shape and take the form of deep bowls. The body of the vessel is decorated with a series of bands made up of incised lines, strokes, or indentations (Figure 2a, b). Spatulate and denticulate decoration becomes more prevalent later in time. The decoration is highly distinctive and stylized, comprising a variety of distinct but clearly related band-types that have been defined by the excavation team. There are 35 different band-types in all. The more common ones are shown in Figure 3. The vertical dimension of the typology in Figure 3 embodies multiplicity of lines, which increases toward the bottom; the horizontal dimension signifies a tendency toward fragmentation of the continuous linear patterns into rows of spatulate, punctate marks; in extreme forms these entirely supplant the linear incisions.

A chronological sequence has been defined for the occupation of the Merzbachtal on the basis of two different sets of criteria: on the one hand, a seriation of the pottery, the results of which have been divided into 25 chronological intervals (Frirdich 1994); on the other, the detailed stratigraphic and spatial analysis of the sites themselves (Stehli 1994). These two sequences have been correlated with one another (see Frirdich 1994), a process that involved linking the seriation intervals to the independently defined phases. For the first six phases, based on site stratigraphy and spatial analysis (phases I–VI), only two band-types were used with any frequency. All the ceramic assemblages from these phases fall into a single seriation interval because they cannot be distinguished from one another. In the analyses that follow phases I–VI are therefore grouped together. It is estimated that this must have been a period of several generations (Frirdich 1994:354). The chronological analysis has demonstrated that the site of Langweiler 8 was the founding settlement in the area, established most probably by a colonizing group of the first farmers in the region. The other sites were subsequent foundations, in most if not all cases likely to have been established by groups splitting off from the initial settlement at Langweiler 8, which was itself occupied throughout the period, until the area was abandoned.

Frirdich's catalog tabulates the data for six settlements within the Merzbach micro-region in terms of the number of vessels possessing a particular band-type by pit, site, and seriation interval; some of the sites have only small numbers of vessels and display large lacunae along the time dimension. For this reason it was decided to restrict attention to the two most comprehensive data sets, those for Langweiler 8 (LW8) and Laurenzburg 7 (LB7), which together account for 75 percent of the total Merzbach corpus. The two sites are ca. 1 km apart, and their ceramic

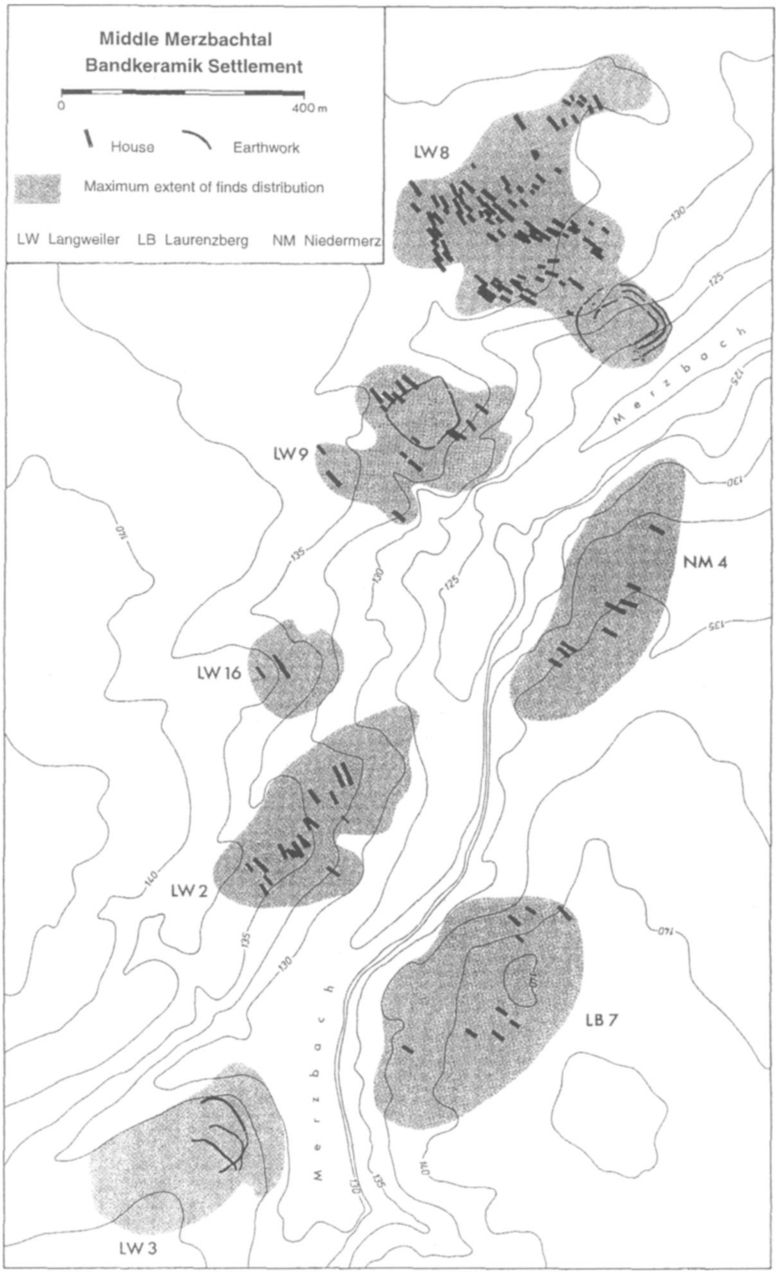


Figure 1. The distribution of Bandkeramik settlement in the middle Merzbach valley. Rectangles mark houses; other features are earthworks. Grey areas indicate maximum possible extent of finds (from Lüning and Stehli 1994)

profiles are extremely similar (Frirdich 1994:261; Mattheusser 1994); the counts from the pits were amalgamated to produce a single phase by phase count for each site. Analyses were carried out on each site separately and also with the two sites amalgamated.

Testing the Relevance of the Neutral Model

The most detailed account of the implications of the neutral model for cultural change is that given by Neiman (1995:9–14), and it provides the basis for that presented here. The object of the account is to

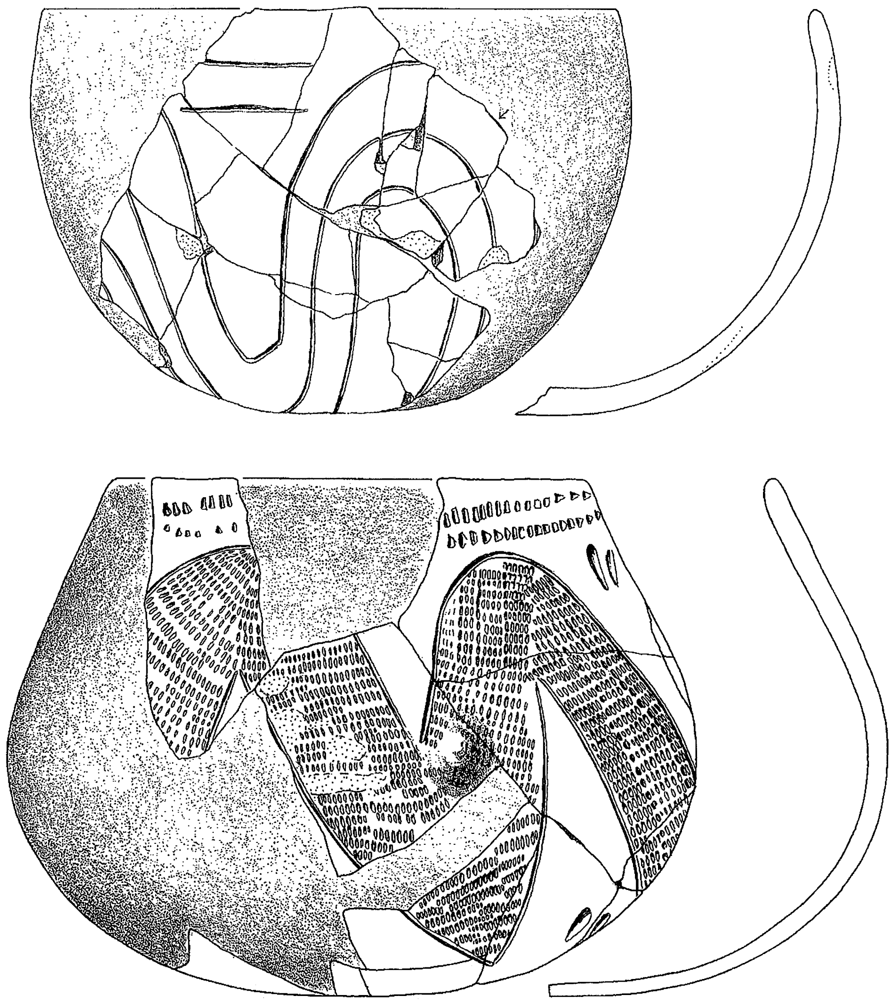


Figure 2. Examples of early (upper) and late (lower) Bandkeramik vessels from the Merzbach valley (from Lüning and Stehli 1994, plate 6.3 and 29.7).

give an intuitive sense of the logic behind the mathematics that enables us to compare the actual band-type frequencies of the different phases with those expected if the changing frequencies are solely the result of drift processes.

We start with a population of N individuals decorating vessels with a given set of band-types. In a given time period they may repeat what they did last time or copy what another random individual is currently doing. The probability of copying oneself or any other particular individual is the same. In principle, the result of such a process repeated a large number of times is that the relative frequencies of the different band-types remain the same as they were at the beginning. In practice it does not work out like this when we are dealing with finite numbers of individuals, and it is important to understand why. Suppose we are simulating a situation with five individuals and use a random number generator to decide which individual will be copied in a given period: if the random number is between 0 and .19, then individual one is copied, .20–.39 individual two, and so on. It is quite possible that a number between, say, .20 and .39 will be selected more than once. If individual two is copied twice it means that another individual will not be copied at all, so if they have a unique variant it will disappear. Next time round it is the new distribution of band-types being produced by the individuals that is available for copying, so individual two's variant, now being used by two indi-

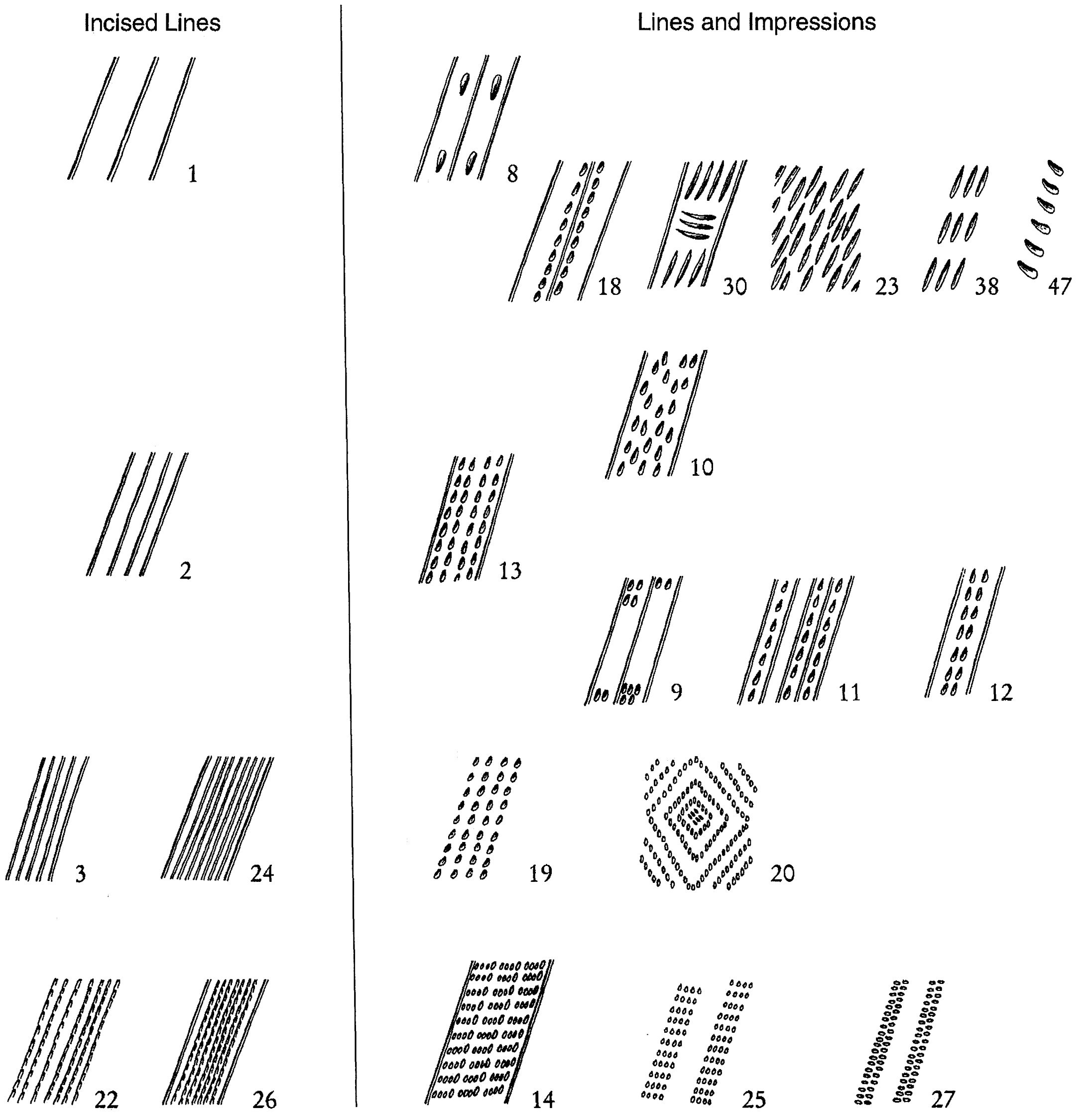


Figure 3. The main decorative motifs used by Frirdich (1994) in her analysis (from Frirdich 1994, fig. 10).

viduals, is twice as likely to be copied, and so on. In other words, this process of random drift eliminates variation, in the absence of innovation, with the result that in the end all individuals will have adopted the same variant, the same band-type in this case; that variant is said to have gone to fixation. The number of episodes required for this to take place depends on the number of individuals; the smaller the number, the faster fixation of a single variant takes place.

If drift is the only process operating, we can obtain a measure of how much variation is left within the population at a given point in time. It depends on the amount of variation at the preceding point and the *effective* population size, N_e, which may be smaller than the actual total population in cases where not everyone is a possible model (Neiman 1995:12 eq. [1]):

$$F_t = \frac{1}{N_e} + \left(1 - \frac{1}{N_e}\right) F_{t-1}$$

where F_t is the homogeneity or uniformity of the population at time t.

This is straightforward enough but it does not take into account the possibility of innovation. Instead of copying its own or another's last example an individual may produce a new version. We can designate the probability of innovation as μ, so the probability of making a faithful copy of some model is $(1 - \mu)$. The probability of selecting two faithful copies of models from the previous copying episode is $(1 - \mu)^2$. The equation for measuring the amount of variation in the population therefore needs to be modified to take this into account (Neiman 1995:14 eq.[2]):

$$F_t = \left[\frac{1}{N_e} + \left(1 - \frac{1}{N_e}\right)F_{t-1}\right](1-\mu)^2$$

If the rate at which innovations are occurring corresponds to that at which variants are being lost by drift, then clearly the amount of variation (in band-types in our case) in the population at any given time will be the same as it was at the time before; in other words, it will be at equilibrium. At equilibrium, if drift and innovation are the only processes operating, then the homogeneity of the population is given by (corrected version of Neiman 1995:14 eq.[3]):

$$\hat{F}_{eq} = \frac{(1-\mu)^2}{\left[N_e - (N_e - 1)(1-\mu)^2\right]}$$

If we make the not unreasonable assumption that the innovation rate, μ, is quite low, then the μ^2 terms are going to be very small indeed so they can effectively be ignored. This leaves us with (Neiman 1995:14 eq.[4]):

$$\hat{F}_{eq} \approx \frac{1}{2N_e\mu + 1}$$

Thus, we now have an expression for the amount of variation in a population in terms of the distribution of different variants (here band-types) within it, if the sole factors affecting their frequency are drift and innovation. It is proportional to twice the effective population size times the innovation rate ($2N_e\mu$) (Neiman 1995:14). As this quantity (which Neiman designates as θ) increases, the homogeneity of the population decreases—it contains more variation. How we can actually obtain an expected value for θ under the neutral model will be shown below.

We are now getting near our goal of being able to compare the homogeneity of the population expected under the neutral variation hypothesis with that which we actually find in our empirical population, in this case the distribution of band-types in the successive LBK phases, because the actual F values for the LBK phases may be estimated empirically in terms of the relative frequencies of the variants in the phase assemblages (Neiman 1995:14 eq.[5]):

$$\hat{F}_{eq} = \sum_{i=1}^{k} p_i^2$$

where p_i is the relative frequency of the ith member of a population of k variants. In fact, the comparison is not made in terms of the F values but of the quantity θ described above. Algebraic rearrangement gives:

$$\theta = \frac{1}{\sum_i p_i^2} - 1$$

In other words, θ will decrease as the sum of the squared relative frequencies of the variants in the population increases. Neiman refers to this estimate of θ, based on the frequencies of variants in the population, as t_F. We now need to be able to calculate the value of θ expected under the neutral model to compare with the estimate given by the band-type frequencies. The LBK data provides a basis for doing this, in two different ways, one following the method used by Neiman (1995) and an alternative (see below).

However, as Neiman points out (1995:15), there is a preliminary issue that needs to be taken into account if we are to use our archaeological data for this purpose. We cannot necessarily assume that the frequency of decorative types in an archaeological assemblage corresponds to the frequency of variants in the past population; it will have been governed, among other things, by discard rates. Nevertheless, Neiman has shown that where assemblages are the product of multiple transmission episodes and multiple discard events, then the assemblage frequency distribution of types/variants will closely correspond to that of the frequency of the variants in the ceramic-producing population from which the assemblage is drawn. Our understanding of the LBK ceramic assemblages used in this study is that they correspond to this situation (see Frirdich 1994; Stehli 1994). In any event, the form and fabric of LBK vessels are remarkably uniform, so there is no need to assume very different use lives.

Neiman's Method as a Means of Testing for Neutrality

In order to use Neiman's method there is one more factor that needs to be taken into account. Even though the LBK sites have been very extensively excavated, excavation was not complete, so our data represent a sample. Furthermore, even if there had been complete excavation there would be grounds for arguing that our assemblages are the outcomes of a population of choices concerning ceramic decoration, as well as a population of discard behavior, and thus represent a sample of these populations (see Shennan 1997: chapter 4). In this situation, then, as Neiman (1995:15) points out, we have to recognize that the distribution of decorative variants in a sample will also be affected by sample size, an issue extensively discussed in the archaeological literature on assemblage diversity.

Neiman makes use of an equation from Ewens (1972) who showed that, if the neutrality assumption holds, then the expected number of different variants in a sample ($E(k)$) is a function of the sample size (n) and the parameter θ, based on the effective population size and the mutation rate, presented above (Neiman 1995:16 eq. [9]):

$$E(k)=\sum_{i=0}^{n-1}\frac{\theta}{\theta+i}$$

Since in a given case we know the observed number of variants (k) and the sample size (n), we can use this equation to obtain an estimate of θ (Neiman 1995:16). Neiman designates these estimates of θ, based on the neutral assumption, as t_E.

Thus, we have two estimates of θ: one, t_E, based on the assumptions of the neutral model, and derived solely from the sample size and the number of variants in the LBK sample; and a second, t_F, based on the actual frequencies of each variant in the sample. Neiman discusses possible ways in which these estimates may be influenced by "artificial" sample-size effects: when samples are very large, t_E estimates may be deflated; when they are small, then t_F estimates may be constrained. It follows that whether t_E or t_F offers a better estimate of θ, it needs to be decided for each specific analysis, depending on the relation between them and assemblage size. Neiman (1995:17) goes on to discuss what sort of pattern one should expect in (t_F-t_E) as a function of sample size, suggesting that the existence of confounding size effects can be detected by measuring the extent to which $(t_F - t_E)$ departs from zero. In his analysis of the Woodland ceramic assemblages, he finds that there is only a very weak assemblage size effect and that the mean of the paired differences (t_F-t_E) is not significantly different from zero. Both measures, in effect, give the same estimate of θ, and Neiman opts to use t_E, the theoretically derived value, for the remaining analyses (1995:18 and Figure 3).

Having established that sample-size effects could be ignored, Neiman went on to look at the way in which within-assemblage diversity in his assemblages related to the effective population size and the innovation rate. He postulated that, to the extent that the innovation rate is affected by the rate of inter-group transmission, as the neutral model would predict, then high levels of within-assemblage diversity mean high levels of inter-group transmission, while low diversity corresponds to low levels. Measures of inter-assemblage similarity should respond in the same way, with high similarity corresponding to high inter-group interaction levels and low similarity to little interaction. It follows from this that "when drift and neutral innovation are at work, we can expect within-assemblage diversity and inter-assemblage distance to be inversely correlated" (Neiman 1995:27). This is what Neiman finds in the case of the lip decoration of his Woodland ceramic assemblages, and he therefore draws the conclusion that in this particular case drift and neutral innovation were the processes at work in the past that produced the observed pattern.

We carried out an analysis of the LBK ceramic data using Neiman's method for obtaining the different estimates of θ. Table 1 shows the values of t_F, t_E, (t_F-t_E) and sample size for the LBK data, together with the correlations between t_F and t_E and sample size. However, in our case the aim was to use the size of the difference $(t_F - t_E)$ to test whether the LBK band-type frequency distribution was significantly different from that expected under the neutral model, if sample size effects could first be excluded.

For the combined data set the smallest LBK ceramic assemblage is >200 in size so it seems unlikely that small samples are having a major impact on t_F, the estimate of θ derived from the actual assemblage variant frequencies. In fact, we can see from

Table 1. Diversity Statistics for LBK Band-Types.

Phase	t_F for LW 8 and LB7 combined	t_E for LW8 and LB7 combined	t_F-t_E for LW8 and LB7 combined	Sample size for LW8 and LB7 combined	t_F for LW8	t_E for LW8	t_F-t_E for LW8	Sample size for LW8	t_F for LB7	t_E for LB7	t_F-t_E for LB7	Sample size for LB7
I-VI	1.48	2.84	-1.36	941.00	1.43	2.82	-1.39	675.00	1.61	2.18	-.57	266.00
VII	2.18	3.77	-1.59	862.00	2.11	3.66	-1.55	566.00	2.31	3.50	-1.19	296.00
VIII	3.89	3.50	.39	388.00	3.78	3.50	.28	216.00	3.88	3.42	.46	172.00
IX	6.28	4.58	1.70	318.00	6.04	4.94	1.10	165.00	6.33	3.60	2.73	153.00
X	7.24	5.28	1.96	368.00	7.32	6.24	1.08	115.00	6.75	5.26	1.49	253.00
XI	7.50	5.10	2.40	339.00	7.67	5.19	2.48	178.00	6.88	5.00	1.88	161.00
XII	6.72	4.86	1.86	746.00	6.81	5.53	1.28	458.00	6.12	4.72	1.40	288.00
XIII	6.04	4.59	1.45	491.00	6.02	4.62	1.40	386.00	5.25	4.56	.69	105.00
XIV	7.28	6.20	1.08	227.00	7.46	6.38	1.08	211.00	3.27	3.00	.27	16.00

Note: see Figure 1 for location and size of settlements LW8 and LB7

Correlation results

Data	Correlation (r)	Probability
Combined sites t_F and sample size	-0.762	0.017
Combined sites t_E and sample size	-0.695	0.038
LW8 t_F and sample size	-0.754	0.019
LW8 t_E and sample size	-0.66	0.053
LB7 t_F and sample size	-0.084	0.829
LB7 t_E and sample size	0.105	0.787

Table 1 that it is actually negatively correlated with assemblage size: the largest assemblages are the least diverse, precisely the opposite of what one would expect if assemblage diversity was constrained by small assemblage sizes. The negative correlation arises because the largest assemblages are the earliest ones, which are the least diverse. Examination of the results for the separate data sets shows that the result arises mainly from the LW8 pattern. For LB7 the correlation between t_F and sample size is close to zero.

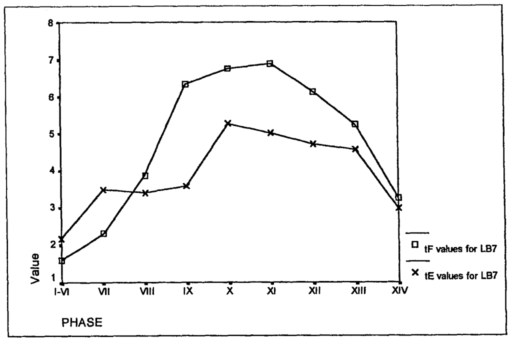
For the combined data set and LW8 the values of t_E, the estimates of θ derived from Ewens's formula, based on the assumption of neutrality, are also negatively correlated with assemblage size in the way that Neiman proposes as a possibility, having the lowest values for the largest assemblages. In such situations, he suggests, t_F is likely to provide a better estimate. In fact, the estimates are close to one another for the largest assemblages. For LB7 the correlation between t_E and sample size, like that for t_F, is again close to zero. We conclude from all this that sample size is not a major factor in accounting for the variation in t_F and t_E values.

Figure 4 shows the plot of t_F and t_E against phase for the combined data set and each of the two sites separately. It is apparent that our results show both similarities and differences when compared with Neiman's: similarity in that the values of t_F and t_E are clearly correlated with one another over time; difference in that, with the exception of the first two phases, the absolute values of t_F and t_E are consistently different from one another. Paired sample t-test results for the difference between the mean values of t_F and t_E for phases VIII–XIV are significant for all three data sets ($p < .01$).

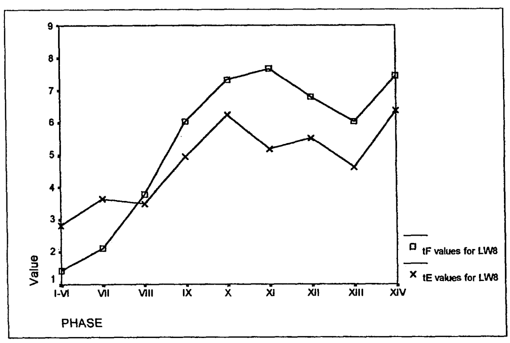
Since in this case the difference cannot be explained in terms of assemblage-size effects, we conclude that there must be another factor involved. Our proposal is that the difference is a measure of the extent to which the transmission process in the case of LBK band-types does not correspond to the neutral model; or rather, while the correlation between the t_F and t_E values indicates that drift was occurring, other forces were also at work.

Direct Estimation of the Components of θ

Does this conclusion gain support from any other approach? It is interesting to compare the pattern in the relation between t_F and t_E and the conclusions



(a)



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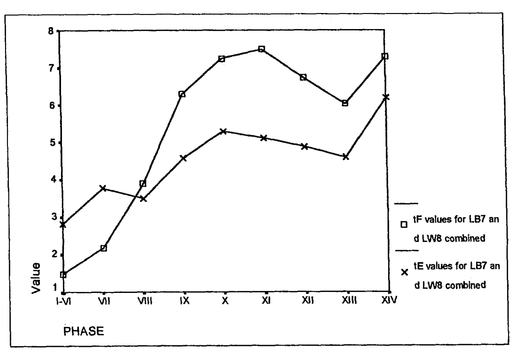

(c)

Figure 4. Plots of t_F and t_E against phase. (a) Combined site data. (b) LW8. (c) LB7. Phases I–VI are grouped together because they are indistinguishable in the band-type seriation.

derived from it, with those obtained by adopting a different approach to obtaining an estimate of θ under the hypothesis of neutrality. We saw above that θ is derived from two quantities, μ, the mutation/innovation rate, and N_e, the effective population size. Unusually, because the sites have been almost totally excavated, the LBK data provide means of estimating these two quantities directly, as follows.

Each vessel is characterized by a particular band-type. The distribution of band-types in the first phase represents the starting distribution of variants. The appearance of new band-types in the immediately following phase represents the occurrence of mutations/ innovations. We can therefore characterize the mutation rate (μ) in one of two ways: the number of new band-types per total number of vessels in a phase, or the number of vessels with new band-types as a proportion of the total number of vessels. Our preference is for the former since it is only the first appearance of a band-type that represents an innovation, but the matter is clearly open to argument and below we present results using both possibilities. The definition of N_e, the effective population size, is also open to a variety of possible definitions. Possibilities include the number of potters, the number of vessels in a given phase and therefore notionally available for copying, and the number of different motifs (band-types) in use in a given phase. Our preference is for the last of these on the grounds that if there is only one kind of "parent," i.e., one band-type, in the population available for imitation, then N_e can only be one, since in effect the different vessels cannot be considered as independent observations. However, below we again present results using all the different possibilities. Our estimate of the number of potters in each phase is based on the number of houses present in each phase of the totally excavated settlements (see Stehli 1994) and the assumption of one potter per house. While objections can clearly be raised against all these measures, we believe that they can give another, qualitative, picture of the relationship between the empirical motif frequencies and those expected under the neutral model, based on an alternative approach.

Tables 2–4 (columns a–e) show the figures on which the empirical estimates of μ and N_e are based for each phase, for the combined data set and for each of the two sites separately. Columns a and b show values of μ (the innovation rate) based on the two alternative definitions described above. Columns c–e show values of N_e based on the three definitions above. Columns g–n represent alternative calculations of θ using different combinations of the values of μ and N_e, given in columns a–e. These are the values we should expect for a population that fits the neutral model of stylistic evolution, given these parameters. The final column shows the value of θ estimated directly from the relative frequencies of the different decorative motifs in each phase, i.e., t_F in Neiman's terms. If the stylistic evolution of the LBK pottery decoration was entirely neutral, the value of θ derived from the mutation rate and the effective population size, and that derived from the motif frequencies, should coincide.

Figure 5a–f and Figures 6–7 a–d show the results of comparing the θ values derived from the motif frequencies, i.e., t_F, with the alternative calculations of θ, using the different combinations of θ and N_e, given in columns g–n of Tables 2–4.

Figure 5a shows the result of estimating θ in the case where the innovation rate is taken to be the number of new motifs per total number of vessels in each phase, and the effective population size is taken as the total number of potters (houses) in that phase. The theoretically expected values of θ are not remotely close to those actually obtained, and there are no innovations in phases VIII or XIII. In Figure 5b the theoretically expected value is based on the same innovation rate as Figure 5a, but this time the effective population size is taken to be the number of different motifs (band-types) in use. The result is very similar to Figure 5a. Figure 5c takes the same innovation rate but the total number of vessels in a given phase as the effective population size. This produces a very erratic set of values but again no resemblance to t_F. Figures 5d–f repeat the different definitions of effective population size but use a different innovation rate, the number of vessels with new band-types per the total number of vessels in each phase. In no case is there any resemblance to t_F. The same is true for the results from the individual sites taken separately, shown in Figures 6–7, which do not include values for the case where N_e is based on the number of houses.

It is apparent both from the results of using Neiman's method and from the direct calculation of estimates of θ using innovation rates and effective population sizes derived from the data, that the absolute values of θ derived from the assumptions of the neutral model and those based on the band-type frequencies in the LBK data are very different from one another. We therefore conclude that we have to reject the view that change in the decoration of LBK vessels can be accounted for by the neutral model, despite the evidence of drift in the correlation between the t_F and t_E values; other forces are also at work.

Table 2. Possible θ Values: LW8 and LB7 Data Combined.

	μ		N_{ef}			Possible Values of θ							
	a	b	c	d	e	g = 2ac	h = 2ad	j = 2ae	l = 2bc	m = 2bd	n = 2be	t_F	t_E
I-VI	18.06	1000	52	17	941	1.87824	0.61404	33.98892	104	34	1882	1.48	2.84
VII	4.64	13.92	17	21	862	0.15776	0.19488	7.99936	0.47328	0.58464	23.99808	2.18	3.77
VIII	0	0	13	17	388	0	0	0	0	0	0	3.89	3.5
IX	9.43	9.43	12	20	318	0.22632	0.3772	5.99748	0.22632	0.3772	5.99748	6.28	4.58
X	10.87	19.02	15	23	368	0.3261	0.50002	8.00032	0.5706	0.87492	13.99872	7.24	5.28
XI	8.85	17.7	16	22	339	0.2832	0.3894	6.0003	0.5664	0.7788	12.0006	7.5	5.1
XII	5.36	26.81	17	25	746	0.18224	0.268	7.99712	0.91154	1.3405	40.00052	6.72	4.86
XIII	0	0	13	22	491	0	0	0	0	0	0	6.04	4.59
XIV	17.62	22.03	10	23	227	0.3524	0.81052	7.99948	0.4406	1.01338	10.00162	7.28	6.2

Table 3. Possible θ Values: LW8 Data Only.

	μ		N_{ef}			Possible Values of θ							
	a	b	c	d	e	g = 2ac	h = 2ad	j = 2ae	l = 2bc	m = 2bd	n = 2be	t_F	t_E
I-VI	23.7	1000	?	16	675		0.7584	31.995		32	1350	1.43	2.82
VII	1.77	10.6	?	19	566		0.06726	2.00364		0.4028	11.9992	2.11	3.66
VIII	4.63	4.63	?	15	216		0.1389	2.00016		0.1389	2.00016	3.78	3.5
IX	24.24	24.2	?	18	165		0.87264	7.9992		0.8712	7.986	6.04	4.94
X	34.78	43.5	?	19	115		1.32164	7.9994		1.653	10.005	7.32	6.24
XI	28.09	39.3	?	19	178		1.06742	10.00004		1.4934	13.9908	7.67	5.19
XII	15.28	63	?	25	458		0.764	13.99648		3.15	57.708	6.81	5.53
XIII	0	0	?	21	386		0	0		0	0	6.02	4.62
XIV	18.96	61.6	?	23	211		0.87216	8.00112		2.8336	25.9952	7.46	6.38

Table 4. Possible θ Values: LB7 Data Only.

	μ		N_{ef}			Possible Values of θ							
	a	b	c	d	e	g = 2ac	h = 2ad	j = 2ae	l = 2bc	m = 2bd	n = 2be	t_F	t_E
I-VI	41.35	1000	?	11	266		0.9097	21.9982		22	532	1.61	2.18
VII	20.27	64.19	?	16	296		0.64864	11.99984		2.05408	38.00048	2.31	3.5
VIII	5.81	5.81	?	14	172		0.16268	1.99864		0.16268	1.99864	3.88	3.42
IX	19.61	26.14	?	14	153		0.54908	6.00066		0.73192	7.99884	6.33	3.6
X	27.67	39.52	?	21	253		1.16214	14.00102		1.65984	19.99712	6.75	5.26
XI	12.42	24.84	?	18	161		0.44712	3.99924		0.89424	7.99848	6.88	5
XII	10.41	48.81	?	20	288		0.4164	5.99616		1.9524	28.11456	6.12	4.72
XIII	0	0	?	15	105		0	0		0	0	5.25	4.56
XIV	0	0	?	6	16		0	0		0	0	3.27	3

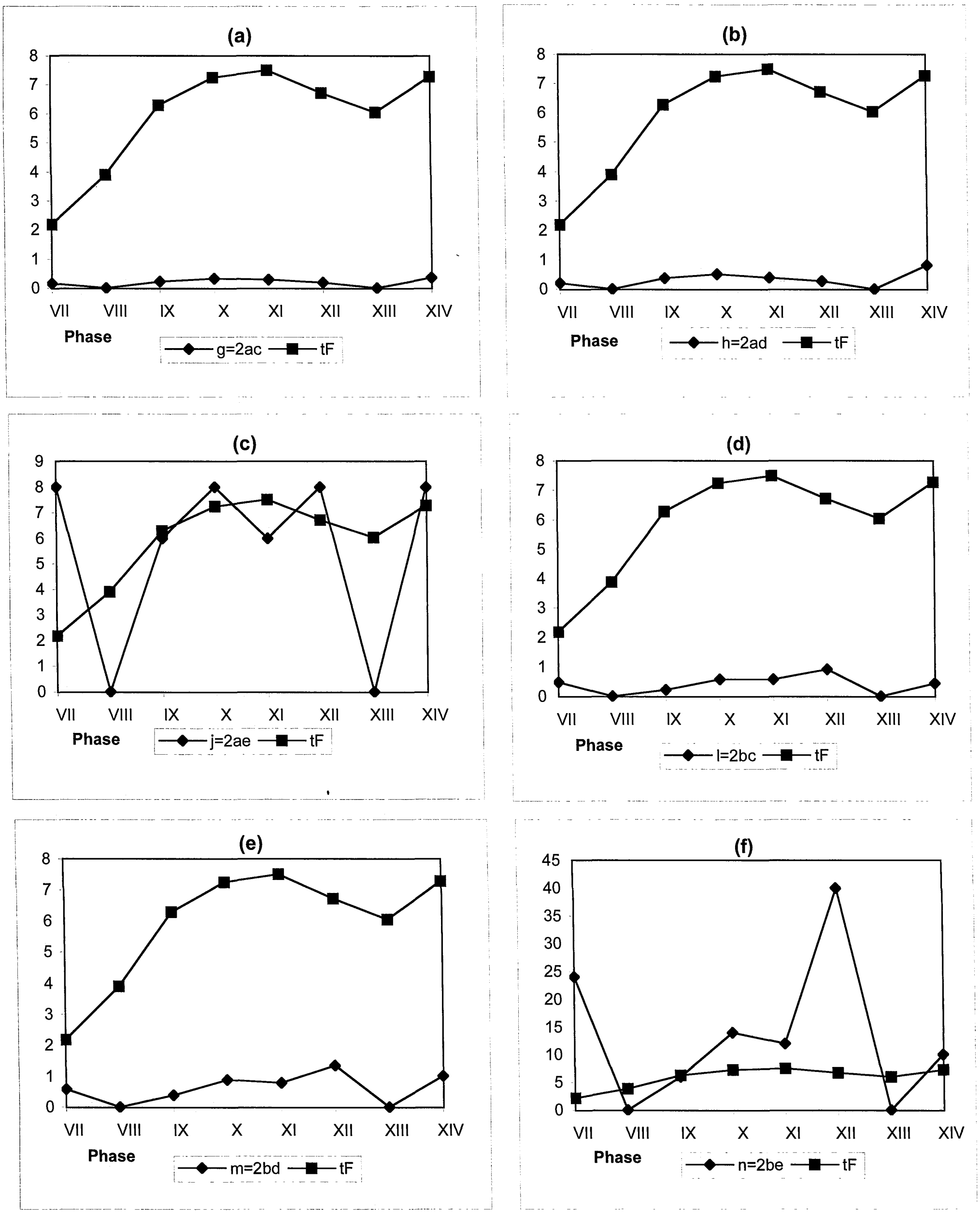

Figure 5. Plots of the values of θ obtained on the basis of the frequencies of the band-types (t_F) and the values expected under the neutral model, against phase, for combinations of various definitions of the mutation/innovation rate and effective population size, using the combined site data in Table 2.

As we have seen, Neiman also suggested that calculating a measure of inter-assemblage difference can be used as another means of testing the drift hypothesis. Under this hypothesis, the later high-diversity assemblages from the two sites should be more similar to one another than the earlier low-diversity ones. However, the assumption that the low intra-assemblage diversity in the early phases should correspond to greater inter-assemblage diversity seems unlikely to hold in this case. This is because if Laurenzburg 7 (LB7) was not actually founded from Langweiler 8 (LW8), then they almost certainly

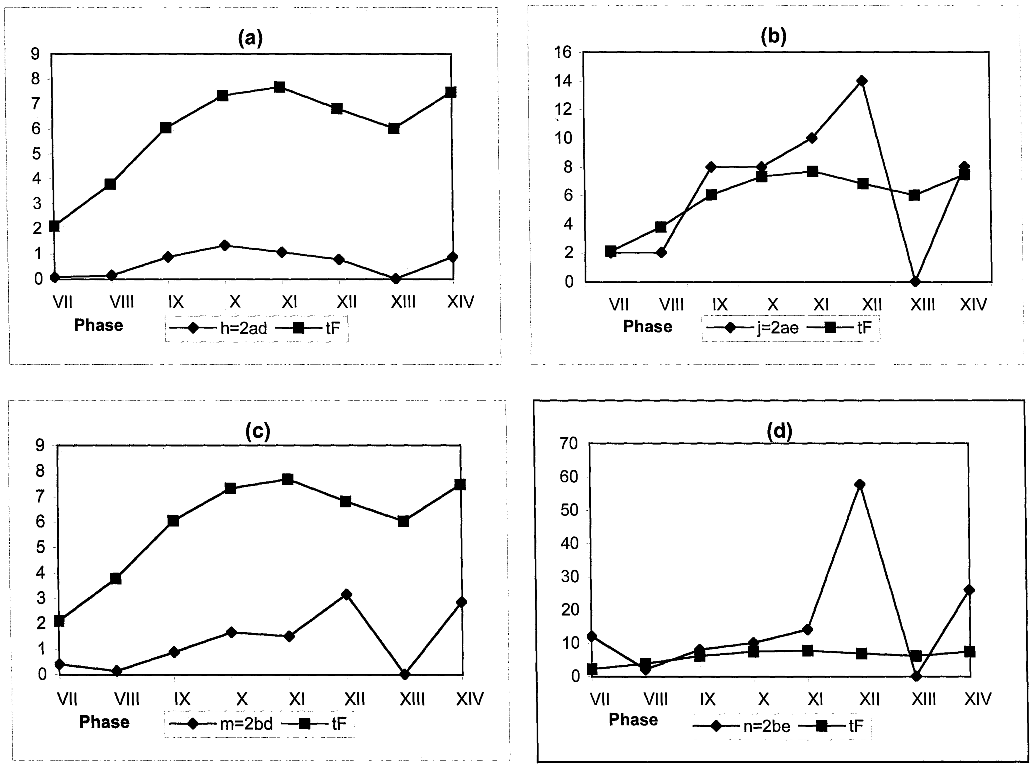

Figure 6. Plots of the values of θ obtained on the basis of the frequencies of the band-types (t_F) and the values expected under the neutral model, against phase, for combinations of various definitions of the mutation/innovation rate and effective population size, using the LW8 data in Table 3.

had a very recent common ancestor; thus one would expect them to start off with ceramic assemblages very similar to one another. In fact, as Figure 8 shows, the two sites start off extremely similar to one another; the difference then increases, but only slightly, and it is not until the final phase that they diverge significantly.

Discussion

It appears that Neiman was correct to express the view that evolution in ceramic decoration may not always follow the predictions of the neutral model, even though it did so in his particular Woodland Illinois example. In other words, we should be very careful about making *a priori* assumptions about what kinds of cultural attributes are or are not under selection, and should use appropriate methodologies to establish this.

Since the LBK band-type frequencies follow the unimodal model and were successfully seriated by Frirdich (1994), the results also show that while neutral evolution may provide one way in which diachronic sequences amenable to seriation may be obtained, it is clearly not the only one. A more appropriate general model of what is going on here may be to see such decorative variation as a kind of cultural "quasi-species" (Eigen 1992), mutating and exploring a possibility space under weak selection (Wilkinson 1997).

Given that the neutral model does not fit the patterns in the LBK band-type frequency data, including the shift in the nature of the quasi-species if we want to think in these terms, what are the processes relevant to explaining them?

For phases I–VII we have no clear evidence that the distribution of band-types differs from that predicted by the neutral model, although there is perhaps a suggestion of a bias against novel variants, in that values of t_F are rather less than those of t_E in these phases; in other words, the assemblages may be less diverse than the neutral model predicts. However, the fact that the values of t_F in the later phases are *significantly* greater than those of t_E indicates that the distribution of vessels across the different band-types

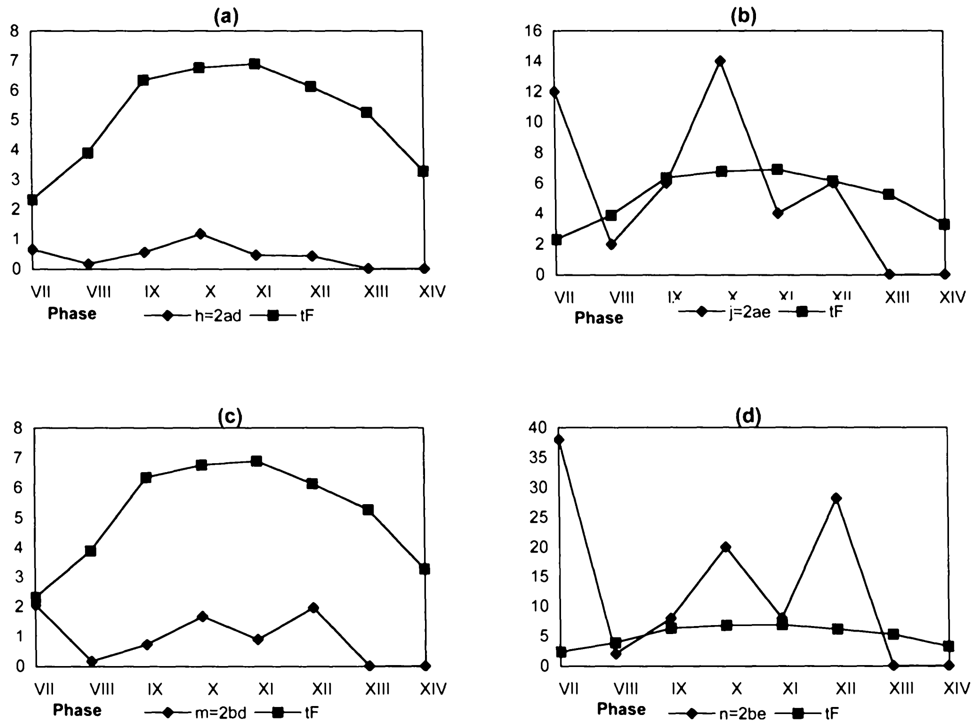

Figure 7. Plots of the values of θ obtained on the basis of the frequencies of the band-types (t_F) and the values expected under the neutral model, against phase, for combinations of various definitions of the mutation/innovation rate and effective population size, using the LB7 data in Table 4.

is more even than it should be. This points to a bias in favor of novel variants, relative to drift.

In this context it seems appropriate to examine the suggestions made by Frirdich (1994), the author of the study whose data have been the subject of this analysis of stylistic neutrality, although she herself did not consider the possibility of a neutral model.

As we saw earlier, her seriation of the band-type data showed that the structural/stratigraphic phases I–VI were extremely uniform, and that phase VII was also very similar to the preceding phases; virtually only two band-types were used. It is estimated that this must have been a period of at least five generations (Frirdich 1994:354). Likewise, she noted that in the following phases, VIII–X, there was a rapid increase in the number of different band-types and the earliest ones decrease in prevalence. Frirdich (1994:355) argued that the long-lasting uniformity in the use of a small number of traditional band-types that characterized the early phases of occupation was maintained by the imposition of strict social norms on band-type choice and that the rapid change that followed represented a relaxation of such norms. Our results do not provide conclusive evidence for or against the imposition of strict norms in the early phases, but do suggest that the change that occurred during the later phases was an active preference for novelty, in the form of negative frequency-dependent bias (Boyd and Richerson 1985), rather than simply a relaxation of previous constraints.

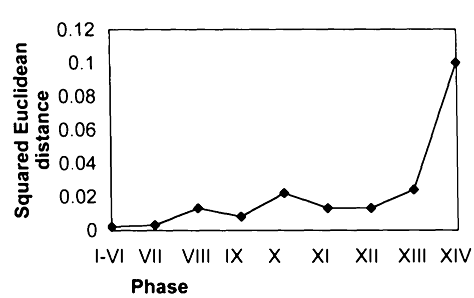

Figure 8. Plot of the squared Euclidean distance between the LW8 and LB7 assemblages by phase.

Interestingly, the move toward a pro-novelty bias in the transmission of band-types at the two long-lasting sites analyzed, including the founding site, Langweiler 8, did not take place in step with the developing colonization of the Merzbach micro-region. New sites were already being established in phase V and this process continued through phases VI and VII; between phases IV and VII, the number of contemporary houses also went up, from seven to 16, a number subsequently equaled but never exceeded. Phases VIII–IX, when the switch to pro-novelty or anticonformist bias takes place, are actually a time when the number of houses and occupied sites decreases, to four sites and ten houses in phase VIII, with four sites and 12 houses in phase IX, although in the following phases it gradually increases to a maximum of seven sites and 16 houses in phase XII. Nevertheless, the pro-novelty bias may reflect a concern to establish distinct local identities once the area had more or less filled up, while if ceramic decoration learning rules were only passed on once a generation (cf. Shennan and Steele 1999), then one might expect a lag in the response to increasing pressure.

A cladistic analysis of the relations between all the sites in the Merzbachtal area (see again Figure 1) suggested that in these later phases the distribution of band-types in use at a particular site was related more to that of possible ancestral sites, or to that of the same site in the previous phase, than to the influence of interaction between neighboring sites (Collard and Shennan 2000). This evidence for cultural differentiation is particularly striking given the localized scale of the Merzbachtal sites and the extensive inter-site interaction that can be assumed to have existed as a result. This seems to point to the existence of transmission-isolating mechanisms of the kind discussed by Durham (1992). It also fits in with the results of the intra-site analyses and their indications of a move toward anticonformist bias in the transmission of decorative band-types in the later phases.

Conclusions

Identifying the processes responsible for evolution in attributes such as ceramic decoration is an essential task for the archaeological explanation of culture change. Evolutionary theory provides a basis for powerful methods of achieving this aim in a way that is not simply a consequence of individual paradigmatic preferences. Using the methods developed by Neiman and some extensions of these, we have shown that the mechanisms relevant to change in the LBK are not the same as those operative in the Illinois Woodland. Although the methods are based on the assumption of neutral evolution, they do not inevitably lead to the conclusion that change in decoration is solely a result of innovation and drift. Rather, they provide a base line of enormous heuristic value that enables the identification not just of neutrality but of alternatives. However, this does not mean that there is a radical separation in the real world between "style," in the sense of neutral variation, and function, in the sense of variation under selection. In the present study it is clear that both drift and selection are operating and it seems likely to us that there is a broad spectrum of possibilities between pure drift on the one hand and almost pure selection on the other.

In the LBK case the drift model makes it clear that something else is going on and offers valuable clues as to what it might be. In the later periods individuals apparently used a learning rule that biased them in favor of adopting novel band-types. In Boyd and Richerson's (1985) terms they developed an anti-conformist transmission bias, at a time when the occupation of the Merzbach valley was in a slight recession after having earlier filled up to what was probably its limit. At present it is unclear why the change occurred, although it does go in step with developments that play down the role of inter-site interaction in producing similarities between sites in their decoration distribution. In our view, however, cultural selection processes are involved in these changes, and understanding them requires at least some degree of behavioral reconstruction (cf. Bettinger et al. 1996) as well as the consideration of more traditional archaeological concepts of "style" and its role; but this need not make our approach to archaeology any less Darwinian, or indeed any less scientific.

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