# Cultural Evolution in the Age of Athens: Drift and Selection in Greek Figure-Painted Pottery

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I, Peter M. Schauer, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

# Abstract

Variation in Greek figure-painted pottery has previously been unsystematically described as the result of social, political and art historical influences. In this study we propose that variation arises from the process of copying itself. The neutral model states that if there are no other forces at work, at time t the frequency of a variant in a population of variants will be in proportion to its frequency at time t-1, modified by the probability that new variants might be invented and old ones might fail to be copied each time there is a copying event, a process known as drift. We test the degree to which variation in figure-painted pottery can be explained by this model using evolutionary approaches to archaeology and culture change (Neiman 1995, Bentley et. al. 2004, Bentley et. al. 2007). We develop and expand these approaches through computer simulation.

Using data from the Beazley archive, we created a new database containing a sample of 38,707 Attic figure-painted vases dating from 650 to 300 BC. Within this sample we explore the diversity, distribution and turnover rate of motifs over time, between shapes and across different decorative techniques. We also explore correlations between shape and motif, and examin the variant frequencies underlying the emergence of the red-figured technique. We show that much of the variation in motifs on figure-painted pottery can be explained as being the result of random copying. Where the neutral model is not sufficient as an explanation of observed variation, we show whether selection is due to bias towards novelty or conformity. These results show that an evolutionary approach to cultural change provides us with a powerful tool for assessing previous research and allows us to identify areas in which further research is required.

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# Chapter 1

# Introduction

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### 1.1 Introduction

Over the past 30 years the use of evolutionary models to explain archaeological and anthropological data has grown in popularity and acceptance. Evolutionary archaeology sees cultural phenomena as inherited lineages that are directly affected by processes which govern the evolution of biological systems, such as natural selection and drift (Shennan and Wilkinson 2001: 577). The evolution of evolutionary archaeology has been well documented elsewhere (Maschner 1996, Shennan 2002, Eerkens and Lipo 2005), but we will present the main points here.

Evolution is simply a mechanism for change, which is the differential persistence of transmitted variation. The principal mechanism for explaining why some variants are found at different frequencies from others is natural selection (Lipo *et. al.* 1997: 304). For selection to be operative, not only must variants be transmitted, but at least some of the variants must interact with the environment differentially, with differing effects on fitness. Such traits are described as “selected” because natural selection - in which the likelihood of being transmitted is tied to fitness – is the mechanism by which the frequency of the trait can be explained. This, however, is not the only mechanism by which evolution operates. Much of the DNA in organisms does not code for any functioning genes. Because it has no function, it is not possible for this DNA to interact with the environment differentially (Shennan 2002: 54). This does not mean that evolution cannot account for the frequency of such traits, only that a different theory is needed to explore its variation. This theory is known as the neutral model of evolution (Kimura and Crow 1964, Crow and Kimura 1970, Ewens 1972).

Dunnell (1978, 1980) is credited with having first proposed evolutionary approaches as a way to structure inquiry into the archaeological record (Neiman 1995: 7). Dunnell created a strict dichotomy between artefacts whose frequencies could be explained as being the result of natural selection and artefacts which could not. “Style denotes those forms that do not have detectable selective values. Function is manifest as those forms that directly affect the Darwinian fitness of the populations in which they occur” (Dunnell 1978: 199). In this definition, because style does not make a difference to fitness, selection cannot act upon it.

This definition addressed what until then had been a fundamental difficulty in explaining the archaeological record in evolutionary terms. Much of the archaeological record is made up of artefacts which would be described as “stylistic”, and evaluating these using the cost/benefit analysis of evolutionary models was not productive, as no selective advantage could be perceived between one variant and another (Dunnell 1978: 192). While advances were made in the application of evolutionary theory throughout the 1980's, especially in the area of cultural transmission (the mechanisms by which culture is transmitted between individuals and groups) (Boyd and Richerson 1985), it was not until Neiman's (1995) analysis of Woodland pottery that a precise methodology for analysing the changing frequencies of stylistic artefacts was introduced.

The problem remained, however, of how to make a distinction between a “functional” variant and a “stylistic” variant. Methods proposed for doing so are based on the temporal patterning of the archaeological record. The assumption has been that stylistic variants will increase and decrease stochastically in relative frequency while traits under selection will increase in frequency until they are fixed (O'Brien and Lyman 2000). It has also been suggested that seriation can be used to differentiate the two, as stylistic variants conform to a unimodal distribution over time, as a result of the rise and fall in the relative frequency of types arises from the stochastic character of neutral transmission (Lipo *et. al.* 1997: 310). However, these distinctions are unreliable, as Shennan and Wilkinson (2001: 578) describe, because fixation and unimodal distributions can arise from other evolutionary processes. O'Brien and Lyman (2000: 90) suggest that the presence of a trait may be functional, but its state at any given time may be stylistic. They give the example of decorated door mouldings, the decoration of which serves the function of a signal of wealth, but the particular form of that decoration is stylistic. The difficulty with this approach is that it is based on prior assumptions with no clear process for determining that different forms of decoration have no differential payoff. Rather than the strict dichotomy proposed by Dunnell (1978), Shennan and Wilkinson propose that there is a broad spectrum of possibilities between pure neutrality on the one hand and almost pure selection on the other (Shennan and Wilkinson 2001: 592).

In spite of these difficulties, there has recently been a great deal of interest in testing real world data against the neutral model in order to determine whether variation is more due to random processes or selection. In simplest terms, the neutral model states that, if there are no other forces at work, at time t the frequency of a variant in a population of variants will be in proportion to its frequency at time t-1, modified by the probability that new variants might be invented and old ones might fail to be copied each time there is a copying event. This means that variation in real world data can be accounted for by the interaction of three simple processes: copying (the reproduction of a variant), innovation (the addition of a new variant) and drift (the failure of some variants to be copied).

The neutral model has been successfully used to explain variation and distribution in pottery (Neiman 1995), baby names (Hahn and Bentley 2003), dog breeds (Herzog *et. al.* 2004), patent applications (Bentley *et. al.* 2004) and the turnover rate of the Billboard music charts (Bentley *et. al.* 2007). Each of these studies has used one or more of several different methods to test the predictions of the neutral model. These include assessing the diversity of variants in a sample (Neiman 1995), the overall distribution of variants (Bentley *et. al.* 2004), and the turnover rate of variants (Bentley *et. al.* 2007). In each case, a measurement of these parameters is made from the data and is then compared with expected values for those parameters based on computer simulation. Computer simulations are used in this research because the theoretical underpinnings of the neutral model are derived from population genetics techniques which assess the diversity of populations at single points in time (Kimura and Crow 1964, Crow and Kimura 1970, Ewens 1972). Archaeologists, however, are interested in how these parameters change over time (Bentley *et. al.* 2004: 1444). We will explore each of these methods in detail in chapter 2.

In some applications the neutral model has not been found to be sufficient to explain observed variation. Two recent studies, Shennan and Wilkinson (2001), which examined LBK pottery and Kohler *et. al.* (2004), which examined Southwestern pottery, reject the neutral model. In both cases, however, the rejection of the neutral model allowed existing hypotheses to be re-evaluated from a more informed standpoint. In Herzog *et. al.* (2004), the neutral model was not rejected, but a significant outlier was identified, thus revealing more about the sample than would have otherwise been evident. These studies illustrate that even when the neutral model is not a sufficient explanation for observed variation, it can provide a basis from which to evaluate existing explanations.

The neutral model fulfils several roles not met by other theoretical approaches. It is able to account for the variation  in samples without reference to any force external to the process of copying,  innovation and the failure of some variants to be copied, by chance alone. As such, the model provides a baseline assessment of a sample, against which other theories can be tested. If the neutral model can account for the variation in a sample, then theories which introduce more complex, historically contingent factors, external to the process of copying, should be re-evaluated. When the neutral model cannot account for the variation observed in a sample, we can then examine why the model was rejected for clues about which alternative hypothesis may be more likely, and determine whether new research is needed to explain a result. Most importantly, the neutral model provides researchers with a vital tool for exploring samples whose distributions, diversity and turnover rate cannot be accounted for using the evolutionary cost/benefit analysis that has proved so effective in other areas of human culture (Bentley *et. al.* 2007: 151).

The neutral model allows scientific research to progress into areas of cultural variation in which transmission is the strongest factor in determining variation. The model reclaims much ground which some perceived as having been ceded by Dunnell's style/function dichotomy. This was partly due to Dunnell's (1978) deeply unfortunate choice of terminology in describing artefacts not undergoing selection as “style” as well as the lack of an analytical framework with which to analyse “style” (since provided by Neiman (1995)). When Dunnell published his description of the “fundamental dichotomy”, there was already a substantial literature on “style” and its meaning, both within archaeology and in other fields such as art history. To suggest, even unintentionally, that artefacts which could not be accounted for by selection would be best dealt with using this literature undoubtedly contributed to a delay in the development of a scientific theory of variation in artefacts not subject to selection. Recent studies are in the process of correcting this. As Bettinger *et. al.* (1996: 159) write “style is too important and too interesting to leave to structuralists and post-modernists.” Evolutionary theory is “the only scientific theory that explains change” (Lipo *et. al.* 1997: 304), and must be used if we are to develop an understanding of how variation arises in artefacts not undergoing selection.

In the work which follows, we apply the neutral model to one of the largest and oldest sets of cultural data, Greek figure-painted pottery. The material under examination was produced between 650 BC and 300 BC, and comprises painted figure motifs on the surface of pottery. These motifs vary in their frequency both across shapes and over time. These changes are recorded as part of Beazley's project to attribute known vases to painters (Beazley 1956, Beazley 1963, Beazley 1971). Webster (1972) explores the distribution of motifs recorded by Beazley, and shows relationships between use, shape and motif, but does so with minimal quantification and with no statistical analysis, so it has been difficult for more recent scholars to build on this work. More fundamentally, there has been a consistent lack of interest in figure-painted pottery scholarship of issues such as variation, temporal patterning and transmission. This has meant that our understanding of these processes in figure-painted pottery are largely unscientific, small scale and difficult to evaluate. Nowhere is this more clear than in research which addresses a change in technique which took place at the end of the 6th century, when the formerly dominant black-figure technique gave way to a new technique known as red-figure. Explanations given for this transition range from art historical theorising (Robertson 1992) to unsubstantiated claims about the influence of export markets (Boardman 2001). We will argue that variation in both motif and technique arose predominantly from the process of copying itself. We will use the neutral model to explore diversity, distribution and turnover rate of motifs, and will then apply our results to the transition from black-figure to red-figure.

In chapter 1, we will give a brief description of Greek figure-painted pottery and its production in and around Athens between 650 BC and 300 BC. We identify the changing frequencies of motifs as the key issue of our study. We also describe the change between black-figure and red-figure around 525 BC as being an event which an evolutionary approach is well suited to address. We will also examine previous quantitative approaches to this material and will challenge the notion that figure-painted pottery cannot be examined using quantitative approaches. We will show not only that quantitative approaches to figure-painted pottery are possible, but also that they are necessary. In chapter 2 we will fully explore the methods used in our analysis of the neutral model. These include an analysis of variant diversity using methods from Neiman (1995), an examination of variant distributions and their fit to a power law, using methods from Bentley *et. al.* (2004), and an exploration of variant turnover rate using methods from Bentley *et. al.* (2007). We will show that existing methods for rejecting the neutral model based on diversity and distribution alone are not sufficient, and will describe a new computer simulation which provides a required objective comparison for statistical analysis. In chapter 3 we describe how the data for this study were obtained from the Beazley archive. As will be demonstrated, this was a difficult and time consuming procedure which was divided into four parts. First the data had to be acquired. Then errors in the data had to be corrected. Once the data were free of errors we had to identify variants to use in our analysis. Finally a procedure had to be established to obtain the frequencies of each variant according to the needs of our analysis. In chapter 4 we present the results of our neutral model analysis. We divided our sample of 38,707 figure-painted vases into 10 different shape categories plus one sample with all shapes included. Within each shape sample we divided the sample into the two main techniques: black-figure and red-figure, as well as an additional sample combining both techniques. Each of these samples was then divided into 10 date categories according to each pot's classification in the Beazley archive. When samples with no data or insufficient data were eliminated, we were left with 171 independent neutral model tests, all of which were tested for diversity and fit to a power law. We summarise these results at the end of chapter 4. In chapter 5 we further explore motif frequencies, proportions and turnover rates, including an analysis using the neutral model of turnover from Bentley *et. al.* (2007). As will be shown, using these techniques we identify several motifs as conspicuous outliers in the sense of Herzog *et. al.* (2004). In chapter 6, we will examine the technique frequencies behind the transition from black-figure to red-figure. In chapter 7 we discuss motif outliers in the context of our neutral model results. We also examine the change from black-figure to red-figure in the context of the neutral model and our quantitative approach in general. We will show that it was by no means inevitable that red-figure became popular, and that chance could have played a greater role than has previously been appreciated. We then conclude in chapter 8 with some remarks on the future of the Beazley archive and propose some methods by which further advances can be made in the scientific study of figure-painted pottery.

There is much more that could be done with this approach to figure-painted pottery. Within the limits of the present work it is our intention to show not only the utility of the neutral model specifically, but also of quantitative approaches more generally. We will show that such approaches are compatible with much previous research, as we can not only address existing problems, but we can also pose new questions whose very existence is obscure without a quantitative perspective.

## 1.2 Research overview

This research addresses two issues relating to Greek figure-painted pottery:

- Through what process was variation in motifs created?
- What can these processes tell us about the transition from black-figure to red-figure in the late 6th century?

Both are questions fundamentally about transmission, which the neutral model is ideally suited to address. Before we pose these questions, however, we will briefly outline the background history of figure-painted pottery and its manufacture.

All of the pottery included in this study was produced in and around Athens between 650 BC and 300 BC. Athens began as one city-state among many in the Greek peninsula. As the region emerged from the "dark ages" following the end of the Mycenaean civilisation, the city-state became the basic unit of political organisation in the ancient world, and comprised an autonomous civic centre and its surrounding lands (Osborne 1996a: 19-51). The distribution of city-states closely followed the locations of Mycenaean citadels, but when exactly the system came into being is obscure, as before 500 BC dating of Greek history is unclear and record keeping sparse. As Osborne states, it is not that no history of archaic Greece has come down to us, rather no such history was ever written (Osborne 1996a: 5).

Despite the very limited character of textual primary sources, the archaeology of this period is extensive and well studied, and much of what is known comes from pottery, particularly that deposited in graves (Osborne 1996a: 82). Archaic pottery in this period was designed to serve the same purposes it would serve for many succeeding centuries; the storage and management of water, wine, oil and granular solids and as an offering at shrines and temples and for the deceased. Basic shapes were created for these purposes, including cups, kraters, hydria, and amphorae, which would remain relatively constant while the techniques used to decorate them changed (Boardman 2001: 15). Athens became a major producer of pottery, but so did many other cities, and trade around the Mediterranean was increasingly active.

Trade in pottery in the Archaic period enabled contact between workshops of the East and those in Greece, giving rise to new techniques and styles including black-figure itself. The black-figure technique was developed in Corinth as a means of decorating small aryballoi (perfumed oil vases) and soon became used for cups (Boardman 2001: 32). The technique was copied by Athenian potters in the early 7$^{th}$ century BC (Boardman 2001: 44), and by the mid 6$^{th}$ century BC Athenian black-figure exports are to be found in neighbouring Etruria, the Greek colonies and other parts of Greece itself (*ibid.*: 55). Perhaps as a result of these exports, local production of pottery outside Athens diminished and was maintained only in a few places for special purposes (Sparkes 1996: 10). Corinthian pottery was still produced and even imported into Athens, but interest in figure painting on vases in Corinth was greatly reduced.

Figure painting on vases is first observed in the decoration of monumental vases placed on graves in Athenian cemeteries (Sparkes 1996: 4). These were the largest works of their day and some from a cemetery in Athens were up to 1.25 m high (*ibid.*). Burial competition among the elite was so extensive that Solon, the Athenian lawmaker, is said to have introduced laws specifically designed to curb such activity. The use of monumental figure-painted vases to mark graves stopped when they were replaced by the dedication of *kouroi* (large figure statues)(*ibid.*: 214), but interest in figure painting had by this time spread to all types of pottery.

By the end of the 6$^{th}$ century BC, Athenian pottery was now being exported in great quantities but economic relationships did not translate into political unity, as Greek cities maintained their local independence (Osborne 1996a: 243). This would change in the face of an external threat. At the beginning of the 5$^{th}$ century, revolts by Ionian Greeks had led to open conflict with the Persian Empire (Miller 1997: 5). Though supported by Athens in the form of ships and troops, the initial revolts failed to loosen Persian control over Ionia, and served mainly to bring the full weight of the Persian Empire to bear on the Greek mainland. The first Persian invasion occurred in 490 BC and was repelled by an Athenian army at the battle of Marathon (Sowerby 1995: 39). A second larger Persian invasion was then mounted in 480-479 BC and was again resisted by a Spartan force at Thermopylae and the Athenian fleet at Salamis (Sowerby 1995: 40). Following this success, the 'Delian League' was formed to protect cities in the Aegean from further Persian attacks (Osborne 1996a: 351). However, what began as a defensive alliance gradually became an Athenian empire, whose status was confirmed with the battle at the Eurymedon River in the early 460's, where the Phoenician fleet was destroyed. This victory is one of the only recognisable contemporary political events to be recorded in figure-painted pottery (Miller 1997: 13). Athenian success against the Persians confirmed the status of Athens as a major power in the Aegean for the remainder of the 5$^{th}$ century.

The end of the 5$^{th}$ century BC saw the emergence of Sparta as a power to confront the dominance of Athens. The Peloponnesian War was one conflict among many which the Greek world experienced between 431 and 338 BC (Austin & Vidal-Naquet 1977: 132). In 404 BC, Athens capitulated to Sparta and was forced to disband its empire. Despite ongoing conflict, there was still a lucrative pottery market, but exports were decreasing in the face of local competition, particularly in Etruria (Boardman 2001: 98). Athens, with the help of Thebes, established an anti-Spartan league in 378 BC (Sowerby 1995: 64), which it attempted to use to regain the control it had in its heyday, but the league collapsed by 355 BC. By this time Philip of Macedon had risen to power and conflict with Persia once again loomed in the Greek world.

The decline of Athens as a major power was already under way and its military and political influence diminished. Other arts, including sculpture and wall painting (Robertson 1992: 236) continued to flourish throughout the subsequent Hellenistic era, but fine vase painting was largely given up by 300 BC, for reasons which are not specific but include an overall decline in demand due to the changing political situation and possibly the emigration of painters themselves (Sparkes 1996: 21, Boardman 2001: 106).

### 1.3 Producers and consumers

The basic unit of production of Greek pottery was the workshop. Here, the entire production of a pot would take place, from shaping in wet clay to firing in a kiln and final painting, and thus all of the raw materials, including water, clay and room to process them with fire and smoke, had to be available in one place (Boardman 2001:139). Because all producers of pottery required these conditions, workshops tended to group together in areas outside or on the margins of urban centres. The workshops of other related industries, such as tile makers and architectural detail producers were located nearby (Cook 1997: 259).

In Athens, where all the pottery in our sample was produced, workshops were concentrated in an area known as the *Kerameikos*, which derives its name from the word for clay, *keramos* (Boardman 2001: 139). The quality of clay available to potters varied from region to region. Sparkes suggests that the actual composition of clay used by potters in Athens was more suitable for the making of fine pots than that of other cities (Sparkes 1991: 8) and that this may have contributed to the spread of fine Athenian pottery across the region. The clustering together of workshops due to similar material demands meant that potters and painters would have known one another's output and possibly even level of sales, just as today a visit by a collector to an artist's studio wouldn't go unnoticed by those down the corridor. A few inscriptions survive which indicate that such rivalry was very much alive in the *Kerameikos* (Vickers and Gill 1994: 97), and may have contributed to a process of elaboration through competition.

While we can be sure of the location of workshops from the locations of excavated kilns, the structure of what went on inside them must be pieced together from clues on the pots themselves. Workshops will have almost certainly started as family affairs, with the trade being passed down the paternal line (Sparkes 1991: 10), usually as a sideline to agriculture. Only in centres of wealth such as Athens would pot making as a full time occupation have been possible (Boardman 2001: 141). Even here though, the number of staff would have been small.

There were two main tasks in the production of painted pottery: the making of the pot itself and the painting of its surface decoration. Pots were made and painted individually, with little sign of factory methods as we would understand the term today (Cook 1997: 259). There were some exceptions, such as the Penthesilea workshop, where it seems pots were decorated in stages by multiple hands (Boardman 2001: 94, Osborne 2004b:79), but this was not the norm. In some workshops there was a clear division of labour between those who shaped the pots and those who painted them, while in others the two tasks overlapped (Webster 1972:41). In some cases potters would supply blank pots to several painters, or several painters would work with several potters (Osborne 2004c: 88). The most typical structure was one or more painters being supplied by a single potter (Boardman 2001: 149).

Not all of the potters and painters in each workshop would have been employed permanently. In many cases it appears that itinerant potters and painters moved from workshop to workshop, sometimes even coming to Athens from areas outside Greece for this purpose (Boardman 2001: 150). The character of the industry was one of fluidity. As Osborne (2004c: 93) states, the strength of the pottery market was such that everything produced was sold, producing little incentive to specialise or move beyond the minimal pairing of one potter and one painter.

The number of painters and potters present in each workshop at a given time is not known. Cook gives the figure of two or three painters per workshop (Cook 1997: 259), while Webster puts the number at 10 to 20 including potters (Webster 1972: 41). Osborne (2004c: 92) describes this figure as having been "plucked out of the air" and states that a figure closer to a maximum of 8 for both tasks is far more likely. Boardman states that there must have been "at least a hundred" painters at any one time (Boardman 2001: 143), as does Sparkes (1991: 11), and adds that there were perhaps 500 individuals at any one time involved in the entire manufacturing process overall (including stokers, bearers and other peripheral tasks). Webster estimates that during the peak of production in the late sixth and early fifth century BC there were about 200 painters and 50 potters working at any one time (Webster 1972: 2). Boardman estimates the total output of figure-painted pottery at its peak in Athens to have been upwards of 50,000 pots per year overall (Boardman 2001: 162). If we accept the suggestion that this was the work of only 100 to 200 painters at a time, then each was producing one pot every one or two days.

From this description, we see that the conditions in the *Kerameikos* were ideal for innovation. Production was concentrated in one area, meaning that distance and communication were not a factor. The rate of production was high, which meant there were many opportunities to innovate and, because sales were evidently brisk, the risks were relatively low. The number of producers was substantial and they worked alongside one another in constantly changing configurations, allowing innovations to be observed and copied.

## 1.4 Changes in figure-painted pottery

The most well studied innovation in Greek figure-painted pottery is the invention of the red-figure technique at the end of the 6$^{th}$ century. Prior to this time, figure-painted pottery was produced in black-figure. In this technique, figures are depicted in slip-painted black silhouettes, which are given interior detail by means of incision through to the red ground of the pot beneath. After firing, the figures appear black, while the background is the red colour of the clay slip. In red-figure, the colour scheme is reversed. The background is painted; the figures are shown in the original red of the fired clay, with interior details shown with painted lines of slip in varying degrees of dilution. Early red-figure retained the incised line of black-figure, but this was soon discarded in favour of a painted line (Boardman 2001: 79). By the mid 5th century, the vast majority of figure-painted pots were produced using red-figure, while black-figure was used only in special circumstances.

There is no consensus in current research about why red-figure was invented and why it became popular. Explanations include art historical necessity (von Bothmer 1972, Robertson 1992, Cook 1997), imitation of other materials (Vickers 1985, Vickers 1987, Vickers and Gill 1994), demands of the export market (Boardman 2001) and general statements which propose no precise function (Willliams and Burn 1991, Sparkes 1996). The difficulty with these explanations is that for the most part they cannot be disproved. For example, how can we assess whether painters required “a medium more subtly expressive” (Cook 1997: 44)? Because fine metal ware tends not to survive from antiquity, how do we assess whether Vickers and Gill are correct in hypothesising that red-figure was invented to better imitate gold figured silver ware (Vickers and Gill 1994)? The similarities are striking, but causality has not been demonstrated (nor disproved, despite great hostility against the suggestion). Only Boardman's assertion that red-figure was a “new line for the growing export market” (Boardman 2001: 79) has been subjected to a quantitative investigation, and this seems to show that the export market was satisfied with whatever it received (Osborne 2004c), so it is difficult to see how it could have insisted on a different form.

This leaves us only with general statements, such as Robertson's observation that the *Kerameikos* was a place of “lively experimentation” in the last quarter of the 6th century BC and that red-figure was simply the style which “took the firmest hold and became the norm” (Robertson 1992: 9). This may be true, but provides us with no understanding of how or why the change occurred.

If changes in technique are not well understood, the changes in motif are even less clear. There were hundreds of scenes and characters from mythology which could be depicted on figure-painted pottery, yet some motifs were very popular, while others appear only a few times. In most previous research, the changing popularity of figures is ascribed to historical contingency. Despite Robertson's assertion that it is "misguided to try to define any precise correlation between changes in art and changes in social and political conditions" (Robertson 1992: 235), many authors look to historical events for clues about the impetus for changes in frequencies of motifs. For example, appearances of Boreas and Pan are linked by Webster (1972) to their mythological involvement in the Persian war. Osborne identifies the depiction of Skythian archers as a "call to arms" for the fledgling Athenian citizen army (Osborne 2004b: 52) in the last quarter of the 6th century. Theseus is identified as the Athenian national hero and depictions of him increase in the 5th century, when Athenian power was at its height (Shapiro 1991b: 136). Beyond the changes in the frequencies of individual motifs, there were also shifts in the entire repertoire of characters used in figure-painted pottery. After 500 BC, there was a shift away from older, heroic motifs towards more "Dionysiac" motifs, such as satyrs, maenads, Dionysos and Eros (Shapiro 1990). This has been interpreted by some (*e.g.* Neer 2002) as a reflection of wider political events, specifically a focus more on the individual and their role in society.

Such descriptions abound in research on Athenian figure-painted pottery. The implication is that all motifs are a symbol of something else, which, if identified, can tell us why some things are popular and others are not. Yet we know that it was very rare for contemporary events to be depicted in pottery directly (Webster 1972), and that it is tenuous to decode mythology as symbolic of events not directly depicted (Osborne 1983). The use of imagery as a sort of text depends heavily on the interpretative ability of the makers and users of pots, which, as Sparkes points out, has probably been overestimated by scholars (Sparkes 1996: 130). Interpreting the frequencies of motifs as reflections of events is an impossibly unwieldy method for identifying the source of variation in figure-painted pottery. If a story fits a particular interpretation, this does not mean that anyone in the original loop – the painter, purchaser or second hand user – shared our view. Like theories about the development and popularity of the red-figure technique, theories of changing motif frequency based on symbolic iconography rely more on their appeal to shared intuitions of modern historians than any systematic texts to confirm of reject them.

Making matters more difficult is the absence of a quantitative approach to figure-painted pottery. This makes claims even more difficult to evaluate, as simple statements of the changing popularity of some motifs are often unsupported by the simplest quantification, rendering subsequent conclusions even more difficult to support or refute. In the next section we will examine quantitative approaches that have been applied to figure-painted pottery, and will show why an entirely new approach is required. Our research will explore the frequency of motifs used in figure-painted pottery across a range of shapes, and will use the neutral model to explore the extent to which the process of copying itself can account for observed variation, distribution and turnover of motifs. After we perform this analysis, we will return to the question of the transition from black-figure to red-figure, and describe how the process of copying alone is enough for such transitions to take place.

### 1.5 Sources and applications

There are three data sources which can be drawn upon for quantitative studies of figure-painted pottery. These are the *Corpus Vasorum Antiquorum*, Beazley's lists and the online Beazley Archive. Some authors have developed their own lists based on a combination of these and their own observations from museum collections and other first hand observation. Because these lists are usually very small, constituting at most a few hundred vases listed in an appendix, they do not represent a basis for third party quantitative research.

The *Corpus Vasorum Antiquorum*, or *CVA* as it is known, was developed by Pottier in 1919 as an international project to publish the thousands of vases in museum collections (Stansbury-O'Donnell 2006: 26). For every museum collection containing Greek figure-painted pottery, an edition of the *CVA* is produced. The first was for the Louvre in 1922, and since then there have been over 100,000 entries from museums in 26 countries. The *CVA* includes all forms of pottery, not just the Athenian vases that are the subject of our study, as well as fragments and reconstructions. The *CVA* has been a popular source of data because it contains large black and white photographs of the vases themselves. This allows researchers to make their own judgements about the contents of each scene. For some studies this is an essential component.

Beazley's lists, as published in the Attic black-figure Vase Painters (*ABV*) (Beazley 1956), Attic red-figure Vase Painters (*ARV*) (Beazley 1963) and *Paralipomena* (Beazley 1971) are the result of years of direct study of the source material by Beazley himself. The lists contain descriptions of pots as they are attributed to known painters. This comprehensive work has been the basis for many studies. These works include "about two-thirds of all known Attic vases" (Stewart 1995: 87).

In 1979, the Beazley archive began to computerize its records. This has been an ongoing process, and has over time expanded to include not only Beazley's original lists, but also a vast number of additional published pots. At present there are 75,451 entries of the fabric type "Athenian", though as we will see, around half of these are either fragments or are incomplete to the point of being unusable for analysis. The true value of the Beazley archive is that it contains 14 different searchable data fields, any of which can be combined to yield the desired results. As we will see, however, it does not exactly work as intended, but with some refinement is an unparalleled resource for quantitative studies of figure-painted pottery.

Previous quantitative studies of figure-painted pottery have used each of these sources in a variety of ways. A common approach is to identify a figurative motif or set of motifs which are of interest, then trace the frequency of appearances of that motif over time. Comparisons can also be made with other attributes of the vases, including the shape, technique and provenance, where known. This is the approach used in Webster (1972), still the largest and most important quantitative study of figure-painted pottery to date. In this work, Webster uses Beazley's lists to create lists of all sorts of motifs by shape, technique, date, and purpose. No other work has been as ambitious. Stewart (1995) uses the Beazley lists to track the distribution of divine pursuits and abductions over time. He defines date categories by subjective stages of development in figure painting (Stewart 1995: 87). Osborne (1997) uses Beazley's *ARV* to study the frequency of types of motifs (myth vs. non myth) on white ground lekythoi by painter (Osborne 1997: 18). The *ARV* data source is used again in Osborne (2004c). In this study, Osborne explores the relationships between painters, shapes, motifs and provenances. The paper also includes some simple network diagrams which illustrate collaborations between potters and painters and show lines of hypothesised influence. Woodford and Loudon (1980) examine the frequency of various ways of depicting Ajax carrying the body of Achilles and Aeneas carrying Anchises (Woodford and Loudon 1980: 26). Boardman (1979) uses Beazley's lists to show the frequency of red-figure and black-figure vases at various provenances by date (Boardman 1979: 36). Some authors use Beazley's lists in conjunction with another data source. Shapiro (1990) examines the frequency distribution of older and newer themes, in order to explore whether a perceived shift in tone can be supported by data. In order to do this, the study uses Beazley's *ABV* and *Paralipomena*, as well as Brommer's *Vasenlisten zur greichischen Heldensage* (Brommer 1973) and other recently published additions.

The *CVA* is used in studies in which Beazley's descriptions of the decorations on each pot are not adequate for the question under consideration. Stansbury-O'Donnell (2006) examines the frequency of vases showing scenes involving “spectators”. While some descriptions from Beazely include action terms, “spectators” are not always described, and so the author used photographs from the *CVA* to build his own lists of vases which include spectators (Stansbury-O'Donnell 2006: ch. 2). Comparisons are then made between genders of spectators, find context, shape and date. The study also includes a comparison of these sources with a random sample from the online Beazley archive (Stansbury-O'Donnell 2006: 47). The results of this random sample and the author's own *CVA* based sample are shown to agree (*ibid.:* 50) in frequency across the key parameters under examination. Goossens and Theilemans (1996) use the *CVA* as a data source to examine the frequency distribution of athletes and the relative popularity of different types of sports. As in the Stansbury-O'Donnell (2006) study, the authors wanted to make their own identifications about each sport, as Beazley often records the motif type “athlete” without indicating the type of athletics depicted. As will be discussed, the Goossens and Theilemans (1996) study is of special interest for its use of statistics. Osborne (2001) combines a sample from the *CVA* with information from Beazley's *ABV*, *ARV* and *Paralipomena* in order to explore the frequency of mythological and non-mythological motifs by provenance as a way of assessing the influence of the export market.

The online Beazley archive has been used as a data source in very few published studies. Bažant (1991) compares the results of an earlier study of motif frequencies using Beazley's lists with a study of the same motif frequencies using the online Beazley archive. In a collection of line graphs he shows that the results are very much the same. Yet this early confirmation of the online Beazley archive's utility has done little to encourage authors to use the resource. No study we have been able to locate uses it as an exclusive data source. Instead, authors use it as backup for other studies, as in the Stansbury-O'Donnell (2006) study. Osborne (2004c) uses it only to give total numbers of vases by date (Osborne 2004c:53), in a study of motif frequencies which is otherwise based on Beazley's lists and  Lissarrague's catalogues.

Other studies which present frequencies as part of their argument rely upon their own lists or other sources. Osborne (1996b) uses Rosati *et. al.* (1989), a work which supplements the lists found in Beazley's *ABV* in a study of the distribution of shapes and painters by provenance. Matheson (1994) uses the catalogues published by Hayashi to show the frequency distribution of scenes of the “mission of Triptolemus” by date (Matheson 1994: 363). Miller (1999b) examines the frequency of subjects associated with komasts by painter period (archaic vs. classical), but uses her own lists of vases to do so. Oakley (1998) also uses his own lists to examine the frequency distribution of red-figure skyphoi of the Corinthian shape, by date and provenance. Because these lists were formed to answer these questions specifically, it is not possible to use them in other studies.

No one data source is perfect for all purposes. As Stansbury-O'Donnel states:

> “The difficulty of using one main source, whether the Beazley lists, the *CVA*, or the Beazley Archive, should not, however, limit the effort to use descriptive data to find patterns in vase-painting and to interpret its themes. Within their limitations, such studies provide information about the incidence of iconographic subjects on a broad scale and give us a glimpse of the visual language of images, focusing as much on viewers as on artists. All such efforts, however, should eventually be tested against a more comprehensive, representative, and searchable database as it emerges in the future” (Stansbury-O'Donnel 2006: 27).

We eagerly await this comprehensive database and would be keen to advise on its construction specifications. Until then, however, the Beazley Archive, flawed as it may be, is the best data source available for quantitative studies of figure-painted pottery. Not only is it already available in electronic format, but because it contains many records from the *CVA* within it, as well as many other additions, it is the most comprehensive source of data about figure-painted pottery.

## 1.6 Quantitative?

Of all the above approaches, the Goossens and Theilemans (1996) study is of special interest because, to our knowledge, it is the *only* study which has been published which includes a statistical test of any description. All other quantitative approaches we have discussed show correlations only. No tests are offered as to the statistical validity of those correlations. Even these correlations are difficult to judge because unless we know the frequency of *all* motifs in a given class (for example, all mythological motifs), then it is impossible to form even a subjective opinion about the data presented. There are exceptions, including Webster (1972), Boardman (1979) and many of Osborne's studies (*e.g.* Osborne 2004c), which frame frequencies in the total number of known vases for each period, but the majority of studies present their results as tables without context.

It is hardly surprising that the Goossens and Theilemans (1996) study failed to spark any interest in the application of statistics to figure-painted pottery. For some reason, it was intended to be published in two parts. Part A appeared in *Babesch* volume 71, but part B, which was meant to include the discussion of the results shown in part A, never appeared.[1] Therefore, the study sank without a trace, and was cited only once as far as we can determine from the literature databases.

It is tempting to read the fate of the Goossens and Theilemans (1996) study not as the result of some accident of publishing, but rather as a result of the substantial bias against quantitative approaches which exists in figure-painted pottery scholarship. One does not have to look hard to find vociferous opposition to the application of any type of quantitative analysis to figure-painted pottery. Marconi (2004b: 39) takes great pains to avoid saying what percentage of Athenian vases in Etruria depict warriors because of the "severe limitations to the use of quantitative studies applied to Athenian vases". This is because statistics on Athenian vases "generally rely, more or less directly, on Beazley's lists. These are not, however, lists of all surviving Athenian vases at the time of the publication of *ABV* and *ARV*, but only those vases which Beazley felt able to attribute to a painter or a group" (Hannestad 1991: 213 in Marconi 2004b: 39).

It is a shame, however, that Marconi did not finish the paragraph which begins with the above quote from Hannestad (1991). Had he done so, we would be left with a very different impression – one which does not forbid the use of Beazley's research in quantitative studies. The overall focus of Hannestad's paper is whether Beazley's research can be used in quantitative studies. The test she presents of this is whether bias can be detected between samples from different provenances and whether there is any bias in Beazley's overall sampling in red-figure when compared with the output of known excavations. To determine whether this is the case, she adds up the total number of vases present at five locations (Vulci, Tarquinia, Gela, the Agora and the Acropolis) as recorded in the *ARV*, and then calculates the proportion of each shape at each location. Her results

1 We sent several emails enquiring about the missing part B to the staff of *Babesch* and the authors that could be tracked down, but these went unanswered.

(which are presented as percentages of shapes at each provenance – no formal test is carried out) show *only* that the frequencies of shapes are different at different locations. Hannestad hypothesises that this is due to differences in the find locations themselves – tombs as opposed to populated areas appear to show different frequencies of shapes. This means that we must be cautious when inferring a regional preference for a shape, as we may be comparing an excavated marketplace with a tomb, and this may not be comparing like with like.

Hannestad then goes on to compare the frequencies of shapes at the Agora and Acropolis recorded by Beazley with what is known from the excavation reports of those locations. It is worth quoting the result of this comparison in full:

> "We may, of course, ask whether such statistics [the frequency of shapes at the five locations above] have any validity at all. First and foremeost, being based on Beazley they include only that part of the preserved material which Beazley felt able to attribute to a painter or a group. However, a comparison between the red-figure material from the Agora and the Acropolis based on the archives of the Agora excavations and on *Graef-Langlotz* on the one hand and on Beazley on the other shows that the percentages of the most common shapes *do not differ substantially*, and I think that this result may also be applied to other sites, and that what is included by Beazley in the *ARV* (and I should stress that this does not apply to *ABV*) is at least as to the most common shapes representative of what has actually been found on a site." (emphasis ours) (Hannestad 1991: 213).

Hannestad's emphasis on not including the *ABV* in her support of Beazley's sampling methods in red-figure is due to her previous research (Hannestad 1987) which showed that the proportion of different shapes included in Beazley's black-figure lists are not the same as the proportion of shapes known to have been found at some locations. This difference between what is recorded in lists of pottery and the "real" list that went into the ground over 2,000 years ago is a very common source of opposition to quantitative approaches. For example, in his study of depictions of Zeus, Arafat states that "because of the partial nature of the evidence, I have preferred not to compile any statistics about the relative frequency of occurrence of Zeus compared with that of other gods" (Arafat 1990: 178).

However, all archaeologists must deal with "partial evidence". All excavated artefacts, including  figure-painted pottery, represent a sample of a larger population. The question is how well our sample accurately reflects characteristics of the source population. This has been a source of ongoing debate in the archaeological literature (*e.g.* Grayson 1970, Hall 1981, Bettinger 1981, Scheps 1982). As Shennan (1997: 51) describes, "the problem is that *we do not know* how representative the sample is of the population, or how closely the statistic obtained approximates the corresponding unknown parameter, and our goal is to make inferences about various population parameters on the basis of known sample statistics." The solution to this persistent problem is relatively straightforward. As Grayson (1970: 103) describes:

> "[Imagine] a large population composed of a high percentage of trait X and a small percentage of trait Y. Since the instances of X greatly outnumber those of Y, the chances of drawing an X on any one sampling trial will be much greater than those of drawing a Y. If a large sample is drawn from this population, then the ratio of X to Y in the sample will approximate that in the population; as the sample size decreases, the poorer this approximation will be, and the more the ratio X/X+Y will tend to overestimate the proportion of X in the population."

In other words, the larger the sample, the more likely it is to accurately reflect the characteristics of the population from which it was drawn. By virtue of its size alone, the sample represented by the Beazley archive is therefore more likely to accurately represent the characteristics of Greek figure-painted pottery than any smaller sample drawn from individual excavations or collections. These characteristics include simple proportions, such as the ratio between a given motif and a given shape, as well as more complex statistics, such as whether random copying can be rejected as an explanation for observed variation. As one of the largest collections of data about artefacts of a single type, in fact, the inferences we are able to make from it are likely to be much stronger than those that archaeologists typically have to deal with. There is, therefore, no reason not to use the data of the Beazley archive for statistical analysis.

Hannestad's criticism is not of Beazley, but rather of those who have sought support from Beazley's data about points which simply cannot be supported with the data available. As an example, Hannestad criticises Giudice (1979) who suggests that the distribution pattern of a single painter's output across four different locations supports an hypothesis about a purposeful change in Adriatic trade routes in the 5th century. The evidence provided by Giudice could not support the hypothesis proposed, and Hannestad is right to criticise this and similarly slim studies. The problem, however, is not with Beazley. The problem is that previous studies, including some of those listed above, are not well designed, and ask questions of the data which cannot be answered using the evidence included in their design. Hannestad (1991) is not a condemnation of Beazley as a data source, as Marconi has misrepresented it.[2] It is instead a warning about poor use of small samples from a very large data set, a conclusion with which we find no fault.

We suspect that opposition to quantitative approaches based on Beazley arises from opposition to Beazley's methods of attribution, seen by some now to be a fraudulent attempt to create a Renaissance-like system of workshops where none existed. As Hannestad (1991) reports, Beazley was very open about his biases, expressing a liking for and against the objects he studied. However, Beazley's personal attitudes have absolutely no bearing on his recorded observations of motifs, techniques, shapes and estimated dates. Furthermore, the online Beazley archive has since 1979 added thousands of pots to its database which Beazley did not record, further diluting any lingering bias. We accept that provenances and painters need to be treated with caution, but this is a problem with figure-painted pottery as a whole – not Beazley personally or his work. When this bias – the very real bias against Beazley - is combined with a total misunderstanding or lack of knowledge of statistics and what statistics can do for our understanding of figure-painted pottery, then no progress can be made.

Quantitative approaches have never been a common approach to art history or classics. As Osborne describes, "Beazley made no more than casual and implicit use of statistics" and his followers have done no better (Osborne 2004c: 42-43). But, as Osborne goes on: "..by ignoring questions of relative quantity, those who study Greek pottery seem to me to have ignored what is potentially a most important source of information about the relationship between the producer and consumer...They have also...ignored a vital tool by which to distinguish the *exceptional from the normal,and the only means by which it is possible to sort out what exactly needs explaining in Greek imagery"* [emphasis ours] (Osborne 2004c:43). This precisely is the purpose of our study. As we will demonstrate, the neutral model is the ideal tool for determining what requires explanation and what does not.

2 We imagine that Marconi's misreading of Hannestad has not been corrected because the original paper is not in wide circulation. It was published in a non-English volume and is not available electronically.

# Chapter 2

# Testing Neutrality

The neutral model is an attractive explanation for the observed distributions of cultural variants, but testing if the model applies to a given set of real world data is far from straightforward. The neutral model is a null hypothesis. Therefore, we cannot conclude absolutely that it is the explanation for an observed distribution, but methods have been developed to assess the probability and extent of departures from neutrality. These methods reject the neutral model by comparing measured parameters of data samples with expectations based on the neutral model. The parameters used vary depending on the approach. Neiman (1995) uses variant diversity, while Bentley *et. al.* (2004) use variant frequency and Bentley *et. al.* (2007) use variant turnover rate. We will examine each of these in turn and describe how they were adapted for use in this study. We will also describe the methodology used to calculate parameters for analysis from counts of motif frequencies.

## 2.1 Diversity and distributions

Neiman (1995) developed the diversity-based approach as part of an analysis of Hopwell Illinois Woodland ceramic assemblages. The problem presented by this study was how to account for variation in decorative motifs on pottery from 5 localities in two southern Illinois river valleys. The variation under examination occurred in decoration applied to a band around the top of cooking pots, with 26 equal alternatives identified. The results showed that variation in decorative bands was dependent on inter-group distance, but it is the calculations used to reach this conclusion that are of interest to us here.

Neiman's key contribution was to adapt methods from population genetics for assessing the distribution of neutral alleles and use them to describe samples of neutral cultural variants. In the absence of selection, drift and mutation are the only forces controlling the diversity of a population. Drift describes a failure to be copied, for purely chance reasons, so that, in the absence of innovation, diversity is reduced until finally only a single variant exists in the population (Neiman 1995: 14). Innovation counteracts this process by introducing new variants into the system and increasing diversity. In a population at equilibrium, these two forces - innovation and loss through drift - will balance one another.

The mathematics of the neutral theory in population genetics show that if a given trait is not subject to selection, then the diversity of variants of that trait is a function of the effective population size and the mutation (innovation) rate. Diversity scales linearly with theta, a parameter defined as twice the effective population size times the innovation rate (Neiman 1995: 14). We should therefore be able to reject the neutral model by using theta to compare the diversity of a given sample with a measure of the level of diversity expected under the neutral model.

Neiman outlines two methods for estimating theta for a given dataset, one based on the proportional frequencies of variants in the data and one based on the predicted number of variants in relation to sample size, on the assumption of neutrality. This methodology is an adaptation of algorithms described by Ewens (1972) and Crow and Kimura (1970) for assessing the homogeneity of neutral alleles in a sample. The homogeneity of variant frequencies within a population at equilibrium (where drift and innovation are equal) is a function of population size and mutation rate. This can be expressed as follows:

$$\hat{F} \simeq \frac{1}{2\mathrm{N}_e \mu + 1}$$

where F refers to variant frequencies, $N_e$ is the effective population size, and μ the mutation rate (Neiman, 1995: 14). Population size might refer to the number of variant producers (as in Kohler 2004), the population of variants available to be copied or the number of individuals or items which are available to carry the variant (for example, the number of pots). Shennan and Wilkinson (2001: 587) use all three definitions. Mutation rate (μ) refers to the rate of innovation and describes how often new variants are created (we describe our own approaches to these parameters below). From this we see that variation (the reciprocal of homogeneity) is proportional to twice the effective population size times the innovation rate ($2N_e\mu$), a quantity Neiman refers to as theta ($\theta$). As theta increases, so does variation. To test the neutral hypothesis we compare values of theta rather than F.

The first of Neiman's two methods for calculating theta is based on the observed frequencies of variants in our sample, as follows:

$$t_F = \frac{1}{\sum_{i-1}^{k} p_i^2} - 1$$

This means that $\theta$ will decrease as the sum of the squared relative frequencies of the variants in the population increases. Following Neiman (1995), this estimate of $\theta$ is referred to as $t_F$ as it is based on the actual frequencies of variants in our sample.

The second measure of $\theta$ is based on the assumptions of the neutral model. Following Ewens (1972), Neiman shows that under conditions of neutrality, the expected number of different variants in a sample, described by the notation E(k), is a function of the sample size (n) and the parameter $\theta$, which, as above, is a function of the population size and mutation rate. This can be expressed as follows:

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

From our sample we can determine the observed number of variants (k) and the sample size (n), so we can use this equation to obtain an estimate of $\theta$. This estimate, based on the neutral assumption, is designated $t_E$. While $t_F$ has an analytical solution, $t_E$ must be calculated by iterating k (the number of variants). In the past this was done by hand, but we have written a visual basic script which performs this operation automatically, allowing us to perform thousands of calculations in very little time.

To reject the neutral hypothesis, we compare the value of $\theta$ given by the actual frequencies of variants in our sample ($t_F$) with that given by the assumption of neutrality ($t_E$) as follows: ($t_F$ -$t_E$). If $t_F$ is greater than $t_E$, then there is more variation in the sample than would be expected under neutrality, and the sample was subject to a selective force which actively increased the amount of variation, such as a bias for novelty. This was the result found by Shennan and Wilkinson (2001) in their sample of LBK pottery. If $t_F$ is less than $t_E$, then there is less variation than would be expected under conditions of neutrality, and the sample was subject to a selective force which actively decreased the amount of variation, such as a bias for conformity. This was the result found by Kohler *et. al.* (2004) in their sample of ceramic styles found on the Pajarito Plateau, New Mexico. If $t_F$ is equal to $t_E$, then the actual frequencies of variants match those predicted under conditions of neutrality and the neutral model is not rejected. For his Woodland ceramic assemblages, Neiman showed that the two approaches gave the same result (Neiman 1995: 19). He was then able to show that in his case study periods of high stylistic diversity were associated with high levels of intergroup transmission while low diversity corresponded to low levels of intergroup transmission (Neiman 1995: 27). The amount of contact was shown to be dependent on intergroup distance. Intergroup distance will, of course, not be a factor in our case study, as all of the potters and pot painters were to all intents and purposes in one location: the *Kerameikos*. As we have seen in the introduction, painters were commingling continuously, with ample opportunities to copy innovations or create their own.

Kohler *et. al.* (2004) and Shennan and Wilkinson (2001) compare measurements of diversity based on theta as a test on their own. However, no study has yet shown that $t_F$ and $t_E$ will indeed be statistically indistinguishable in a sample created through a process of neutrality. If we do not know that this is the case, then we are not in a strong position to claim the opposite, that differing estimates show a departure from the predictions of neutrality. This is not a problem for Neiman, as his1995 paper uses these calculations simply to find a good estimate of theta, against which to compare inter-group distance. However, questions could be raised about the results of Shennan and Wilkinson 2001 and Kohler *et. al.* 2004. Because the relationship between $t_F$ and $t_E$ has not been demonstrated, it is difficult to use this assumption to reject the neutral model.

## 2.2 Frequency

Bentley *et. al.* (2004) go some way towards resolving this issue. In their paper, rather than examine the diversity of variants, they analyse their frequency. They propose that the neutral model may explain power law distributions of cultural data. In such a distribution, the probability of measuring a particular value of some quantity varies inversely as a power of that value (Newman 2005: 323). In simplest terms, a power law distribution of variants means that there are many uncommon variants and a very few popular variants that are many orders of magnitude more popular than the majority (Bentley *et. al.* 2004: 1443). This relationship between probability and value, also known as Zipf's law or as a Pareto distribution, has been observed in hundreds of studies, including natural and man-made systems ranging from crater size on the surface of the moon to the number of telephone calls received in a day.[3] As Newman (2005) describes, there is no consensus regarding the cause of these distributions and why they are so frequently observed. The most likely candidates are the Yule process, a rich get richer scenario in which variants grow in proportion to their frequency (Yule 1925), and self organised criticality, in which systems organise themselves into scale-free distributions as a result of internal rules (Bak *et. al.* 1987).

In order to test whether the frequency of variants follows a power law, Bentely *et. al.* (2004) present a simple computer model which produces a frequency distribution for several different combinations of N and mu. The computer model creates a population of N individuals, each with their own variant. At each time step, each individual copies a variant from all available possibilities, or creates a new variant at a likelihood equal to the mutation rate. When the model is stopped, they create a frequency distribution from the final distribution of variants. For each of an intriguing range of cultural data sets, including baby names and the same LBK pottery examined in Shennan and Wilkinson (2001), the distribution corresponds to a power law on a log log scale.

Generating expected values of key parameters using a computer model is one of the few methods that can be used to test the neutral model. However, with only 5 runs for each combination of N and mu, the sample size of model results used in Bentley *et. al.* (2004) is too small to be a reliable indication of expected values. An average of 1,000 results, for example, would be far more likely to produce a real indication of the expected values for a given combination of N and mu.

We used both of the above techniques to analyse the diversity and distribution of motifs in our database of pottery. Input data was generated using the search scripts described in chapter 3 using a selector that filtered technique x shape x date x motif. However, without evidence that in a neutral system $t_E - t_F = 0$ and without a standard by which to judge

3 For a complete overview of power law papers going back to 1881 see the list maintained by Wentian Li at http://www.nslij-genetics.org/wli/zipf/

slope and r-squared values, we could not proceed. After much experimentation, our solution was to develop a new model, which would produce theta values and r-squared values over thousands of runs. This new model was written from scratch in python by Adam Powell in the Department of Biology at UCL. It was designed specifically to address the problems outlined above. Using this new model, we were able to create tables of critical values for given values of N and mu, and use these to assess whether the neutral model could be rejected in each of our 33 samples of motif frequencies on Greek figure-painted pottery. Before presenting the results of this comparison, we will first discuss the mechanics of our model.

### 2.3 The new model

Our computer model has two basic input parameters: the size of population (N) and the rate at which new innovations occur (mu). We start with two populations made up of N individuals. Both begin at complete homogeneity; in one population every individual has their own variant and in the other all individuals have the same variant. At each time step, all individuals copy a new variant from another individual, including the possibility of reproducing their own variant, or they may innovate at a likelihood equal to the innovation rate set at the beginning of the model. This process is repeated over and over again until the number of variants which fail to be copied is equal to the number of variants introduced through innovation. At this point, the population can be said to be at equilibrium, in accordance with the neutral model. Both of the populations which begin the model are run until they reach equilibrium, and at the point at which they meet the model is stopped. We required each combination of N and mu to run for a minimum of 150 steps, even if equilibrium was reached before this.

From the last step of each run of the model, when the population is at equilibrium, we calculate several parameters. First, we create a power law from the variants present and calculate the r-squared value, the slope and the y-intercept. We additionally calculate the lowest 1%, 5% and 10% of r-squared values, in order to provide a minimum threshold for comparison with real world data. If, for example, our data were calculated to have an r-squared value below the bottom 1% of r-squared values for the same N and mu, then we can reject the neutral model with 99% certainty.

We also calculate the mean $t_F$ and $t_E$ for each of the 1000 runs of the model using the methods described above from Neiman (1995). We calculate the signed and unsigned difference between $t_F$ and $t_E$, along with 1%, 5% and 10% confidence intervals for each, as above. Using these measures we can determine the acceptable difference between the $t_F$ and $t_E$ for a neutral population with a given N and mu.

Using this system, the model was run 1000 times for each combination of N and mu. Combinations included all values from 100 to 1000 with intervals of 100 and all values of mu from 0.01 to 0.1 with intervals of 0.01. We also ran each of the ten mutation rates against N=2000. For N=4,000 and N=8,000, we ran only mu=0.01, mu=0.05 and mu=0.1, which were run 100 times rather than 1000. This was due to constraints on processing time. The combination of N=8000 and mu=0.1 took 12.7 hours to complete 100 iterations. Assuming a constant rate, to complete 1000 iterations would have taken 11.3 days of running the model uninterrupted at full capacity for 24 hours a day. Other combinations of very high and very low mutation were also run for specific combinations found in our data.

Samples from the data are compared with the model to the nearest 100 for samples in which N is less than 1000, and to the nearest 1000 for samples over 1000. Mutation is compared to the nearest 0.01, or to the nearest 0.05 for samples in which N is greater than 4000. Any samples for which mutation is found to be less than 0.01 are compared with N to the nearest hundred and mu=0.001. In all, 159 combinations of N and mu were run, for a total of 153,600 total iterations, with a total run time of 126.2 hours.

### 2.3.1 Theta outputs

As described above, for each combination of N and mu, we calculate $t_E$ and $t_F$. Mean values for $t_F$ and $t_E$ are shown in figure 2.1. It is immediately apparent that as N and mu increase, so does $t_E$ and $t_F$ in the model results. Under conditions of neutrality, theta is entirely determined by these values.

We can get a better idea of the dynamics at work in our sample by comparing the absolute difference between $t_F$ and $t_E$ in our model and in our data, as shown in figure 2.2. We use the absolute (unsigned, that is, the value without a negative sign) difference in theta as opposed to the actual, signed difference in theta because in the initial comparison between the model and data we only consider whether the theta difference is less in the data than in the model. A smaller difference between the two measures of theta indicates greater adherence to the neutral model, as described by Shennan and Wilkinson (2001) and

Kohler *et. al.* (2004). Figure 2.2 shows that as N and mu increase in our model, so too does the difference in theta.

While we expect the individual values of theta to increase as N and mu increase, figures 1 and 2 show that they do not increase at the same rate, and that the difference in theta grows as N and mu become larger. This is because $t_E$ is directly calculated from the population size, and the rate at which it grows in relation to N and mu out-paces the rate at which $t_F$ grows for the same values. Therefore, because $t_E$ will always be larger, we cannot use the assumption that the difference between $t_F$ and $t_E$ will be zero as a test of the neutral model. Shennan and Wilkinson (2001) and Kohler *et. al.* (2004) use this test, but we find no support for the method. If thousands of ideal populations produced in our model do not show a theta difference of zero, then we have no chance to find such a relationship in real world data. Even at the smallest population size (N=100) and lowest rate of mutation (mu=0.01), we find that $|t_F-t_E|=0.92$. Instead, we must consider whether the theta difference in a given sample is within the range calculated for a population at equilibrium, as derived from our model.

To use measurements of theta to test whether the neutral model can be rejected for a given sample, we compare the unsigned difference between $t_F$ and $t_E$ with the unsigned difference between $t_F$ and $t_E$ for similar values of N and mu in our model. Comparisons are made with the highest 1%, 5% and 10% of values for $|t_F-t_E|$. This gives us an index of confidence in our results, with the lowest 1% having the least power to reject a sample and 10% the most. Of the three thresholds, we consider the middle 5% to be the most representative of the sample as a whole, and will use this as the primary determination of whether or not to reject the neutral model. If the value of $|t_F-t_E|$ for our data is greater than that of the corresponding sample from the model, then we can reject the neutral model for that case. If we reject the neutral model, then we compare the sample with the mean signed difference ($t_F-t_E$) for the same sample in the model. If the signed difference for the data is greater than that found in the model, then we conclude that the data shows more diversity than would be expected under the neutral model. If the signed difference is less in the data than in the model, then we conclude that the data contains less diversity than would be expected under the neutral model.

For example, the $t_F$ and $t_E$ values for the 550 to 500 black-figure cups sample are $t_F=24.15$ and $t_E=13.66$. This gives us a $|t_F-t_E|$ value of 10.49. In our model, the values of $|t_F-t_E|$ for the same N and mu are 1%=12.096, 5%=9.47 and 10%=7.97. Therefore, at the 1% level, the values generated by the model are not sufficient to reject the neutral model. At the 5% and 10% level, however, the neutral model is rejected. We therefore accept the neutral model at the 1% level, but reject it at 5% and 10%. If we compare the signed difference between $t_F$ and $t_E$, we see that the mean difference in our model is 0.50. The value for the data, $t_F$-$t_E$=10.49, is therefore greater than the value for the model, and we conclude that black-figure cups in 550 to 500 are more diverse than would be expected under the neutral model. We can then use this finding to interpret our result in the context of the existing literature.

### 2.3.2 R-squared outputs

R-squared is calculated by fitting the variant frequencies in the last step of the model to a power law, shown by Bentley *et. al.* 2004 to be the characteristic distribution of the neutral model. As these values are determined only by the relative frequencies of the variants in the population and not the size of the population itself, we expect them to be much less susceptible to sample size effects.[4] Figure 2.3 shows that this is the case, but only above a certain threshold of N and mu. When N is less than 500 and mutation is low, the mean R-squared values derived from the model are also very low. Once mutation and N rise, r-squared values level off around r-squared=0.95.

We can reject the neutral model using the r-squared parameter by using similar methods to our tests of theta, above. For each combination of N and mu in our model we establish the values for r-squared at 1%, 5% and 10% levels, with 1% being the most conservative criteria. Results for the data which show higher r-squared values cannot be rejected, while those that show lower r-squared values are rejected. For example, our 550 to 500 black-figure cup sample shows an r-squared value of 0.98, which indicates an excellent fit for a power law regression. Results for a comparable run in our model show values of 1%=0.89, 5%=0.92 and 10%=0.93. Our value of r-squared of 0.98 is higher than all of these, so we cannot reject the neutral model at any level in this case.

4 Though used by Bentley *et. al.* (2004) as a primary comparison between their model and data, we do not use slope to reject the neutral model in this study. Power laws appear on a log log plot as a straight line, with a slope α. In a true power law, slope remains constant when population changes, indicating that the distribution is scale free. Both the model and comparable samples of our pottery data are indeed scale free. The model slope is nearly constant around -0.5, while that of the data hovers just below -1.5. Only very low N or very low mutation pushes the slope outside of this range. We are at present unable to offer an explanation for the difference between the model and data slope, even in cases (as will be seen) in which the mean r-squared value of the model matches that of the real world data. However, this puzzling result does not affect the rest of the results which follow.

It is important to note that in our example we have obtained different results for the same sample using theta and r-squared methods. This is because the r-squared test and theta test evaluate different parameters for the same data. Variants can still be distributed according to a power law even if they are more diverse than the neutral model would predict, as in this example. The reverse can also sometimes be the case. Despite its limited power to reject the neutral model, the r-squared test is an important complement to the theta test. Fitting data to a power law shows how variants are arranged and immediately reveals how low, medium and high frequency motifs are distributed within a sample. This becomes important when interpreting the results, as will be seen. When the results of both are used together, we get a much better picture of the transmission processes that led to the creation of the sample than with either test on its own.

### 2.4 Making comparisons

These methods were used to create tests for the neutral model using r-squared and theta difference, but we have not yet described the methods used to make these measurements from our figure-painted pottery data. We do so below.

#### 2.4.1 N

At the heart of all calculations above is a value for N and mu, derived from our real world data. In the preceding calculations, “N” represents Ne, the effective population size. In Ewens (1972), effective population size is the number of reproducing individuals in the parent population. As Neiman points out, the effective population (Ne) is likely to be much smaller than the actual population N size, as not every individual reproduces (Neiman 1995: 10). For example, if in a population of 1,000 painters only 200 painters are copied in the next generation, then the effective population size (Ne) is 200, despite the “real” population size being 1,000.

As Ewens (1972) describes, in real-world situations we will not usually be able to determine a value for Ne. This has led to some differences in the way Ne is defined in the few applications of Neiman's work which have emerged so far. In Kohler *et. al.* (2004), Ne is understood to be the population of variant producers. We cannot use this definition in our own study due to problems with estimating the number of painters working at any one time. Due to the way in which the data are structured into 50 year groups, we would also need to know the total number of painters working during a 50 year time period, which would lead us to make estimations of estimations and would not be reliable. We could also use the sum of all variants available to be copied, as used in one set of results in Shennan and Wilkinson (2001), but this would not accurately reflect the realities of the figure-painted pottery market, in which the variants available were not limited to those which appeared in the immediately preceding generation.

The most accurate definition of Ne in this case study is the number of vessels available to carry the variants under examination. In practice, this means that Ne represents the total number of pots which match the search parameters for each sample. For example, there are 1,395 cups in the black-figure and red-figure sample for the date category 525 to 475 BCE, which means that Ne=1395.

### 2.4.2 Mutation

Our other key parameter is mutation, which refers to the level of innovation found in each sample. It is calculated by determining how many new motifs appeared in the sample compared to the previous sample and dividing this total by the total number of pots in that sample. For example, there were 56 new motifs in the 525 to 475 black-figure and red-figure sample and 1,395 cups, as above. Dividing 56 new innovations by 1,395 chances to innovate gives us a rate of 0.04, or 4%.

Whether or not a motif is "new" is determined by checking whether it was present in any previous time step, both for that technique and the opposite technique. For example, we observe Achilles for the first time on a red-figure cup in the 525 to 475 sample. However, it had already appeared for the first time on a black-figure on a cup in 575 to 525. Therefore, we do not count it as a new innovation in red-figure, as the motif is considered to have been copied from black-figure copies of this original motif. This is not an unreasonable assumption given the widely acknowledged porous nature of transmission in the *Kerameikos* both horizontally (between painters) and vertically or obliquely (across generations). Looking back across time steps as well as across the different motifs prevents us from counting the same innovation over and over. This is particularly an issue in the first few phases of red-figure production, in which many motifs appear for the first time in the new technique. If we did not view these as continuations of established traditions executed using new methods, then we would mistakenly ascribe an exceptionally high mutation rate to these periods. Similarly, this method prevents us from over-estimating the level of innovation during the 425 to 375 and 400 to 300 periods, in which black-figure production rose slightly after disappearing almost entirely during the 450 to 400 period. Mutation is not calculated for the first period in each sample, or for any period with a sample size of less than 30 pots.

### 2.4.3 Drift

While not directly part of either r-squared or theta calculations, we will often refer to drift. Drift is the term used to describe the failure of some motifs to be copied from one phase to the next, purely by chance. It is important for us to know how drift and innovation relate in each sample so that we can assess whether the sample is at equilibrium before going on to test for deviations from neutrality. If the sample shows more innovation than drift or vice versa, then we know in advance that it will be very likely to reject the neutral model. We can estimate drift in each sample by adding the number of motifs which appeared in the previous time step with the number of new motifs introduced in the current time step, and then subtract from this total the number of motifs that actually appeared. The number left over is the number of motifs which were not carried over from one time step to the next. Dividing this number by the number of pots in the sample at that time step gives us a drift rate.

For example, in the 575 to 475 black-figure and red-figure cups sample, we observe 109 total motifs, of which 56 were new. There were 65 motifs in the previous time step, which, when added to the 56 new innovations, gives us a total of 121 motifs available. Given that we observed only 109 motifs, we conclude that 12 motifs were not copied, which, when divided by the number of cups in the sample (which, as above, represents the number of opportunities to copy), gives us a drift rate of 0.009, or 0.9% This is very low, but drift can become very high in some samples. For example, during the 500 to 450 period, black-figure cups number only 56, with only 13 motifs between them, none of which were new. In the previous period of 525 to 475, there were 454 black-figure cups and 50 unique motifs. By subtracting the 13 motifs which appeared in the 500 to 450 period from the 50 of the previous sample, we see that 37 motifs were not copied, which, when divided by the 56 cups in the sample gives us a drift rate of 0.661, or 66.1%. When drift is as high as this, it is no longer drift in the classic sense, that is, the random failure of some motifs to be copied. Instead, some outside force must have been acting on the sample, in this case the total replacement of black-figure cups with red-figure cups.

In some cases drift can be more than 100%. This is counter-intuitive, as the painters could not have failed to copy more than all of the motifs available, but can occur when the number of pots in the sample is less than the number of motifs available from the previous sample. For example, in the 425 to 375 red-figure cup sample, we observe 51 pots, 10 total motifs and no innovation. In the previous sample, 450 to 400, we observe 436 pots and 65 motif. If we subtract the number of observed motifs from the number of available motifs, we find that 55 (65-10) motifs were not copied. 55 motifs not copied divided by 51 opportunities to copy gives us a drift rate of 107.8%. This means that for every pot that was made, 1.078 motifs failed to be copied.

Drift can also become negative. This situation occurs when a period of high diversity follows a period of low diversity. For example in the 400 to 300 red-figure cup sample, we observe 216 cups with a total of 27 motifs and no innovation. As described above, in the previous sample, 425 to 375, our sample contained only 51 cups and 10 motifs. Calculating drift as above means that -17 motifs failed to be copied (10-27) and that our drift rate is -7.9% (-17/216)! While the idea of 17 motifs being "*not* not copied" appears to be illogical, it is a side effect of the methods used to count what is a new motif and what is not. The 17 extra motifs are not classed as innovations because they were counted as new in a previous time step. Counting them again here would give us an innovation rate of 7.8%, rather than 0, and would lead us to incorrectly assess this sample.

In practice, both negative and above 100% drift rates indicate a departure from equilibrium, and are indicative of non-random processes. We have tested samples with these features alongside those with more balanced rates of mutation and drift and will show how they do not correspond to the neutral model in the results which follow.

## 2.5 Turnover rate

As a test of the above methods, we employed a third analysis of the neutral model, based on motif turnover rate using the model described in Bentley *et. al.* (2007). As Bentley *et. al.* (2007: 152) describe, the random copying model predicts a regular turnover in particularly popular variants. This is illustrated in an analysis of the turnover rate of popular music charts, the frequencies of first names and the registration of dog breeds in the United States.

As in our model above, in order to evaluate whether or not the neutral model is rejected in a given sample, a computer simulation is used. The model, known as transmissionlab ( http://code.google.com/p/transmissionlab/ ), begins with N individuals, each with a unique variant. At each time step, each individual randomly copies a variant from the previous time step, or innovates a new variant with a probability equal to the mutation parameter set at the beginning of the run. This continues for every time step until the model is stopped, at which point top y lists are created from the distribution of variants in the last time step. The top y list is a list of the most popular variants at given intervals, such as the top 5 most popular variants, top 10, top 15, and so on. According to the neutral model, the larger the list, the more turnover we should see within it. Turnover is defined as the number of new entries to each top y list for a given time interval. The rate of turnover in each list generated from the model is then compared with the corresponding list calculated from the sample data.

While in outline the underlying principles of this model are similar to those used in the model developed for this study, there are a number of key differences. The first is that this model overall is much slower, having been written in javascript for Repast ( http://repast.sourceforge.net/ ) rather than as a native application in python. This means we were unable to run it as many times, in fact running it only 11 times for each combination of parameters, as opposed to 1000 times for each combination as in our previous model. Each of the 11 runs went through 1000 iterations, at which point equilibrium was assumed, whereas our python model included a specific check for equilibrium, and ran until this was reached. The biggest shortcoming of the transmissionlab model is that due to the small number of times it can be run, it produces only a mean turnover rate for each of the top y lists, rather than a range of values. This means that rather than use the output itself as a test for rejecting neutrality, we must compare the outputs using a third test, in this case a linear regression analysis to compare the slopes of the model and the data. These shortcomings are also present in the version of the model used in the Bentley *et. al.* (2007) paper. However, rather than adapt our existing model to produce top y lists, we use the transmission lab model as an external test of our methodologies. We present the results and comparison in chapter 5.

# CHAPTER 3

# DATA GATHERING

## 3.1 Background

Capturing usable data is often the most time consuming and difficult step in quantitative cultural case studies and usually requires more time to complete than the subsequent analysis. This study was no exception. As will be described, turning the Beazley archive into a data set useful for analysis was far from straightforward.

It was immediately apparent that using the online archive in its present form would not be possible for performing a useful analysis. Our main analysis is based entirely on counting the number of appearances of different attributes in different combinations. For example, our main tests of the neutral model are based on the number of appearances of a given set of motifs by date, shape and technique. Millions of individual counts, divided into data sets addressing specific questions, would be required. To complete these searches by hand using the online Beazley archive would consume tens of years.

More importantly, even if it were feasible, the results produced by the Beazley archive in its present state would not be useful for analysis. For example, each pot is classified into a 50 year range which overlaps with those adjacent, for example 550-500, 525-475, 500-450, and so on. The programmers for the Beazley archive misunderstood these to be absolute dates, so that a search for entries with a date from 500 to 450 returns vases in the 550-500, 525-475,500-450, 475-425 and 450-400 categories. Tweaking the search to look for only from 499 to 476 still returns pots in the categories 525-475 and 500-450. Therefore it is impossible to generate accurate counts of desired characteristics by date, a measurement which forms a key parameter of this study.

There are also other factors which limit the usefulness of the current system. The Beazley archive does not respond to operators (*e.g* AND, NOT, OR), which means that search results will always include undesired data, rendering useless any subsequent analysis. The Beazley archive is slow and prone to time-outs, which can mean that complex queries which should be executed in seconds take as much as ten minutes to complete, or fail and never complete. Finally, the very poor quality of the data, which includes misspellings, inconsistencies and data in wrong fields, meant that any serious study based on it would have to include a lengthy period of cleaning in order to guarantee accurate measurements.

For these reasons, it was determined that a local copy of the Beazley archive would have to be created, cleaned and organised. Though arduous and time consuming, there was no other way to proceed.

### 3.2 Capture

Our goal was to create a local database containing all pots in the Beazley archive with Athenian fabric that were not fragments. There are over 45,000 pots in the archive which match this description. Even if it were possible, entering these in our own database by hand at a rate of one per minute would take over 90 eight-hour days, and in practice would probably take ten times as long, due to the slow and unreliable nature of the source. More importantly, recording information by hand increases the likelihood that errors will be made while copying the data. Instead, we developed several ways in which to capture the data directly from the Beazley archive search results.

Two approaches were tried to extract the data. Both were based on methods which read results of searches in the database. A basic search was entered, such as `fabric: Athenian, shape: cups,` and the results viewed as a list. These lists were then copied into our own database. First, we collaborated with Alan Tyler, a programmer for the internet startup Audiojelly.com, to create a script to read the results directly, parse the results and enter these into a secure MySQL database. This method was used for a pilot study of cups, in which over 4,000 rows were captured and analysed. The script was based on a series of rules which placed data in appropriate columns by comparing what was found in the search results with what was expected for each field. Due to the slow running of the Beazley archive, it took several days to complete, but was very effective.

However, this method would not scale to the remaining 41,821 pots spread across 136 shape categories. There were two reasons for this. The first was that the script was continuously timing out, as search results from the Beazley archive take as long as 10 minutes to return. This resulted in partial captures which were not usable for analysis. More importantly, the first script worked by comparing observed and expected data, and placing data in fields accordingly. In the larger analysis there would be many more possibilities for each field, which meant that the patterns developed for cups would not carry over to the remaining shapes. There was no way to anticipate all the combinations without the search results themselves, so after many attempts to fix the existing script it was abandoned and another approach was sought.

Luckily, the unusual design of the Beazley archive itself meant that a solution was forthcoming. The designers of the archive wanted to offer users a drop down menu of search possibilities for each field. To do this, they included in each search field a list of all the possible search terms for that field based on what was in the data. While this meant having an unwieldy 500kb search page that was slow to load, it also meant that the search possibilities were written in simple html, which could be viewed in unrendered form. Within this code was what we had been looking for all along: a list of possible variables for almost every field in the database.

While this solved the problem of what to search for, there was still the question of time outs and incomplete search results produced by working with the live Beazley archive. It was determined that by entering given criteria and then viewing the results as a list, a plain text copy could be made of those results, which could then be fed into a script running on a local machine. This would eliminate all difficulties caused by having to connect to the live website and would at the same time produce more accurate results, as the output could be immediately compared with the source data without going back online and recreating the original search.

First, a copy had to be made of each search result. For each of the 137 non-fragmentary Athenian shapes of interest, a complete search was made, using only the shape name and Athenian fabric as search parameters. These were output in list view in batches of 100 results, each of which was copied and pasted into local text files. This produced 448 text files containing 44,824 lines of data, each an exact copy of the data as presented in the Beazley archive.

Due to unfortunate decisions made during the design process of the Beazley archive, these text files could not then be entered into a new local database. Each record in the Beazley archive contains at least 20 fields, but data is not always present for each field. Rather than display “no data” or “null” for the empty fields, the designers took the unusual step of simply hiding those fields. For any quantitative (and qualitative for that matter) study, the missing information is often as important as the recorded information, and researchers need to know what is absent as well as what is present in order to make an accurate assessment of any search results. This meant that all of the hundreds of thousands of missing data fields would have to be reconstructed and placed correctly.

In addition to leaving fields out, the Beazley archive displays commas both within and between fields in list view, with no encapsulation to indicate whether the comma is a delimiter or  punctuation. Therefore, any script which would process these search results would have to know not only what was a field and what was not, but also how many empty fields should appear between each column within each row, if any.

A new script was written in collaboration with Laurence Tucker, Senior Software Engineer, BBC Future Media & Technology, which would compare the observed data in each row with the expected data for each column, as defined by the terms in the Beazley archive search page. In addition, the script looked ahead a given number of fields in order to determine the position of that data in the database. Each time the script was run it output two sets of data: one set of captures with all the fields in the right place and one set of rejects which did not contain enough information to accurately place the data. By altering how far ahead the script looked in order to identify the column in which a given cell in a row should be placed, it was possible to produce a robust data set of 41,821 rows with only 2,262 rejects. This took 13 runs against all the data to achieve. The script had to be run twice due to problems with the search source code, as described below.

Of these remaining 2,262 rejects, only 200 could be saved by manually comparing the captured data with their record in the Beazley archive, which was obtained by searching by Beazley id. The remaining 2,062 records contained very little data, and were discarded. Without decoration or date they were unusable (though some 3,097 with a decoration but no date were retained for possible use in non-date analyses). The remaining 41,821 rows of data were broken down into 2mb chunks and uploaded into a secure MySQL database.

All searches were performed in October 2006. All results are based on the state of the Beazley archive at this time, though spot checks at the time of writing (April 2008) show that it has not changed perceptibly since then, with the exception that the over-sized search page is now optional (which does nothing to improve the speed of the searches themselves, only the loading of that page). Our local database was completed in December 2006. Captured fields in the final version include the following: `id` (Beazley id number) `fabric` (always Athenian), `technique, sub-technique, shape record, provenance, start date, end date, inscription type, inscription, attribution type, artist, scholar` (who made the attribution or description), `decorated area` and `decoration`. We also captured a number of "code" fields, which are short 3 to 8 letter (but sometimes more) abbreviations of the information in an adjacent field, such as `shape_code: SKY` for skyphos. They appear to be leftovers from an earlier version of the database, when the size of the search string may have made a difference to performance, but serve no purpose in our copy. Because the speed of our database is determined by the number of rows, not the number of columns or even the size of queries, there was no harm in retaining this legacy information.

### 3.3 Errors and Cleaning

Given that our methods faithfully captured the data present in the Beazley archive, the only errors present in the data were those in the data itself. It was quickly observed that these were numerous and persistent. By viewing the data in SQL tables, mistakes which were not apparent when viewing the data in cramped lists or isolated records became obvious, leading all those who came into contact with the data in this form to wonder why the caretakers of this resource never did the same.

The first problem to be observed, however, had to do with how the data was captured. It is well known that some pot shapes, such as cups, contain images both within the bowl of the cup as well as around the outer sides of the cup. In Beazley's work, these are recorded as two separate decorations, and their placement is indicated with a letter or number such as A, B, 0 or I. In the Beazley archive, each decorated area is given its own "decoration" field, in an unordered list running on as necessary. In the list view, however, only one decoration field is displayed, chosen apparently at random from those available for that record. This means that there are additional decorations available for some pots which are not recorded in the local database being used for this study. The only way around this problem would have been to look at the record for each of the 41,821 pots individually and record their details manually, which would have taken months. Not only would this be impractical, it would also introduce the possibility of manual errors being made, and as will be seen there are enough of those in the raw data already.

Upon examination, however, this problem is not as serious as it appears. Not all pots have multiple decorated areas. Lekythoi, for example, which form over a quarter of the entire sample, typically have only one decoration recorded for each, given their slender shape. For those pots that do have multiple decorated areas, the fact that the included decorated area has been chosen by the Beazely archive randomly means that the statistical validity of the sample remains robust, as the decorations common to any one area will not be over represented in comparison to those specific to other areas, even if such a pattern was present. Additionally, each pot now has only one decorated area, which means that when we discuss 41,821 pots we are dealing with only 41,821 decorated areas.

It is not possible to determine how many additional decorations are not included because of this problem. The Beazley archive divides decorated areas into 224 different types, of which 109 are used in our sample. Of these, the top ten by overall quantity ("BD", "A, "B", "A,B", "I", "0", "S", "LD", "UH" and "AB2") account for 31,737 out of the 33,236 pots with a decorated area value. The remaining 8,585 pots do not have a decorated area value. We therefore conclude that while we do not have every decorated area for every pot, the information we do have is representative of the shapes concerned, and will give us an accurate picture of the frequencies of attributes in figure-painted pottery.

Other problems were not so easily resolved. As described above, the parse script which sorted data from the captures into fields in our local database was informed by lists made from the search terms used in the Beazley archive itself. These, in turn, were apparently formed by simply creating de-duped lists of terms used in each field in the archive. This meant that any errors in the search terms produced errors in sorting. Those that had the biggest impact on this study were errors which transposed data from one field to another, thus giving the parse script an incorrect indication of the relationship between some data and fields. As an example, two pots in the original database were listed incorrectly as having the sub-technique "ITALY, CAPUA". Clearly this is the provenance and belongs in an adjacent field, but because it appears in the sub-technique field, it has been entered verbatim into the search menu for sub-technique and therefore appeared in our parse script. Consequently, all pots with a provenance of Italy, Capua and no sub-technique had

Italy, Capua as the contents for the sub-technique field. Other errors included the shape Oinochoe appearing in the search list as "<OPTION SELECTED>OINOCHOE". This is a straightforward coding error which for some reason was never fixed in the search form.

These and a great number of similar errors were observed and fixed before running the parse script. Others only became apparent after the script had been run, which meant the entire parse process had to be repeated. Some were the result of the script being unable to tell in what field given data was supposed to be placed. For example, the term "dog" appears as an artist code as well as within some descriptions. Some inscription types and decorated areas shared codes, such as "B". These had to be manually fixed after the script had already been run and the data imported.

Once all errors relating to the methods used to import the data had been corrected, we were able to turn our attention to errors within the data itself. The first step was to repeatedly sort and search our local database to find anything in the columns which did not fit. The most obvious of the errors found using this method were the numerous erroneous dates which are present in the Beazley archive. These include obviously incorrect dates such as "700", which in the shorthand of the Beazley archive means 700 AD, about a millennia after the last figure-painted pot was made in Athens. Clearly whoever entered the data originally forgot to enter the "–", as the record should have read "–700", or 700 BC. While such mistakes may appear trivial, in a quantitative analysis they are crippling, as they have the potential to artificially skew results. In all other fields, similar non-fitting data were corrected, such as the absence of a shape code for the shape Pyxis A.

In the process of carrying out these extensive cleaning operations, a number of records were deliberately discarded because they could not be used in any subsequent analysis. All records which contained either no date or no decoration, or both, were eliminated from the database. All records with no technique were also deleted. This step was carried out in order to ensure that all records which remained in the database would be useful for analysis, as any unnecessary records would only lengthen the run time of the eventual analysis. Of those that were eliminated, nearly all were lekythoi with very sparse descriptions. There were numerous nearly empty records which contained only a shape, a Beazley id number and a fabric. Given the quantity of these and the fact that these had very low Beazley id numbers, it appears these were some of the first to be entered into the database in the 1980's, and were never returned to with more detail, if there was any to add. Such records could not be used in any analysis and so were eliminated. Other records were incomplete across a variety of columns; some had a start date but no end date, others a decoration description but no decorated area. These were salvaged where possible by manually looking up the source data in the Beazley archive and filling in the missing data if it could be inferred. Records which could not be saved were deleted.

In some cases, actual changes had to be made to the data in order to maintain consistency across different values in the same field. These were design-level decisions which had to be made at this point, prior to analysis or even the identification of variables, in order to ensure that all subsequent results would be complete. For example, a change made to the `description` field included the removal of parentheses from descriptions such as "(The Judgement of Paris)", as these were used inconsistently in the database and could result in identical scenes being wrongly identified as different in a search. Data from other fields which had ended up in the `description` field, such as the scholar or collection, were also moved as appropriate. The `sub-technique` field was particularly riddled with data from the `provenance` and `shape code` fields, which threw whole sets of rows out of alignment. These were also fixed. Misspellings in the `provenance` field were very common, such as "Grecce" for Greece. These were corrected when found. As will be described below, the errors corrected at this stage were only the beginning.

## 3.4 Variables

Once the rows and columns were determined to be free from "garbage" and internally consistent, the next step was to develop working lists of variables to address parameters of interest. These include the shape, date, technique, provenance, painter and description. For each we created a full range of terms which included every possible value for each attribute. We will now examine in detail the methods used to create each variable list.

### 3.4.1 Decoration

The first step in creating our list of study variables was to examine the variables used by Beazley and his followers to describe the decorations on each pot. To do this, we create a list of terms used in the `description` field, and then remove all duplicate terms. The entire contents of the description column was copied from the database into a single column of plain text. All of the commas within the resulting list were turned into line breaks and all remaining punctuation was deleted, giving us a list of all terms as single items. This list was then de-duped using cygwin, a Windows port of the Unix operation space. This produced a list of 2,714 individual terms.

The next step was to transform this list into a set of variables from which our study variables could be selected. Each of the 2,714 terms was sorted into one of 22 different classifications and defined. These categories were not a technical requirement, as all decorations in the in final list will be compared with one another, but they did make processing the lists far easier by providing a first wide pass at the data before drilling down to the specifics of each term. Each term was looked up in either The Oxford Classical Dictionary or the *Realencyclopädie der Klassischen Altertumswissenschaft*. Some terms could not be found in these resources and clues to their meaning had to be sought from less formal sources such as the Perseus Project hosted by Tufts University and the Theoi Project, an online repository of classical texts. Due to their ability to respond to free text searches, these resources proved useful when trying to track down the identity of a particular character based on a mangled misspelling of an Anglicised name.

During the course of this work, any mistakes in the data were noted and fixed. Misspellings were  rife in the Beazley data. For example, consider the following six variations on the simple word “between”:

> BETWEEEN, BETWEEN, BETWEENM, BETWEENSATYRS, BETWWEN, BEWTEEN.

The fact that each of these variations only appeared a few times makes them no less important as mistakes, as every variation constituted an unique variant in our list of 2,714 terms. Furthermore, if simple prepositions were being misspelled to this extent, then multiple spellings of Anglicised Greek names, such as Dionisos / Dionsyos / Dionysos, would have to be treated with particular caution. In many cases, as in this example, only one is actually a misspelling, the others are simply variant spellings of the same name. A further step, therefore, was to create a master list of unified name spellings and change all variations to match. By the end of the list sorting and creation more than 200 mistakes and inconsistent spellings were identified and corrected.

Once all of the 2,714 terms had been classified, defined and, where necessary, corrected, we were able to consider which to include in our final list of variants to use in our study. Because our analysis of decoration focusses on figures only, we selected three primary categories of terms: mythological figures, names and roles.

A. Mythological Figures

Mythological figures are painted figures that can be identified in scenes on pots. The identifications have been done by Beazley and other scholars, based on their own research. In some cases mythological figures can be identified by adjacent painted inscriptions, in other cases the context of the scene or the attributes of the figure indicate who the painter intended them to be. As there is no way to check the identifications made in descriptions, we must accept them at face value.

For each individual, the name was looked up in the above references, then a search for the name was executed on the local database to check the context. If these were found to be in agreement, then the name was recorded and marked for inclusion in the analysis. If the name was found to be an inscription adjacent to a known figure, then it was moved to the "name inscriptions" section, described below.

In some scenes, figures represent a character class rather than a specific individual. For example, a scene may depict a Nereid, but the scholar has been unable to determine which of the 50 Nereids the figure is supposed to be. In some cases the scholar identifies both the class and the name, as in Nereid (Panope), in which case we will get a count in our analysis for both features. In addition to Nereids, other class names include Naiads, Nymphs, Oceanids, Centaurs, Satyrs and Amazons.

Some names are ascribed to more than one mythological figure. For example Aristaios could refer to the god of bee-keeping and other rustic arts, or could refer to a giant. In these cases, it is not necessary for us to make an absolute attribution, only to note that the name is unique and that the possible individuals do not have other names which are also being counted. It is possible in these cases that the scholar who made the attribution also could not tell whom the figure was intended to represent. Sometimes a woman painted on a pot was just a woman, but sometimes the same depiction might be intended to be a Nereid or goddess. It is even possible that the original vase painter himself had no clear idea as to the identity of the figure he was painting, as painters may not have always personally known the stories of the myths they were copying. In these cases, the attribution we assign is another link in a 2,500 year chain of guesses. All that matters for our purposes is that the figure is unique, so the various possibilities for our example of Aristaios do not matter.

Another issue with identifying mythological figures is that they often go by several names. In these cases, the different name indicates a different form of representation for that individual and therefore should be counted separately. The more popular myths included numerous versions of the same figure, for example Dionysos could be represented as himself, the god of wine, or he could be represented as Enorches, in which he is a god of fertility, or as Iacchos, his form when involved in the Mysteries at Eleusis. He even had a younger and older form, sometimes both of which would appear together as the Dionysoi. Demeter, the goddess of grain and agriculture, could be represented as Anesidora, in which she is the sender of gifts, or as Doso, the form of the old woman when she is on earth searching for Persephone. In each of these cases the variant is distinct enough to warrant a unique entry in the analysis.

Variant spellings, on the other hand, were eliminated in the source data. Within the Beazley archive, there appears to have been no agreement as to how to Anglicise certain vowel combinations, such as the first two letters in Aegina as opposed to Aigina, or the last letter in Atalanta as opposed to Atalante. The names are clearly meant to indicate the same individual but each scholar who wrote a description or entered it into the Beazley archive chose a form seemingly at random, meaning that each figure may be recorded in several ways. It would have been possible to connect all the known variants for each name with an OR statement in our database, but this would have been unwieldy in practice, so a single form was decided upon and all deviating forms were changed throughout.

In addition to variants, there were a number of straightforward misspellings, such as “Oddysseus” in place of Odysseus or “Ninotaur” in place of Minotaur. These were corrected when found, as leaving them unchanged would produce inaccurate counts. Because these changes were done individually for each occurrence of each misspelled word, we can be sure that no inscribed names were changed incorrectly.

B. Named Inscriptions

It was very common for pot painters to give the name of a mythological character in the form of a short inscription adjacent to the figure. These name inscriptions are recorded in the Beazley archive as part of the description field. Scholars have normally given the name of the figure and then the inscription, sometimes along with a transcription, such as “Athena (named)” or Athena (named: ATHENAAS). In these cases, Athena has already been counted as part of the core group of known mythological characters in section A above. The named component of the description is not counted separately so that we do not artificially inflate the counts for a given figure by counting both its appearance and name.

In some cases, however, the named inscription referred to a character not recorded by the scholar, as in the following description:

> "HORSEMEN IN THRACIAN CLOAKS, ALL NAMED (DELPHIS, GNATHON, PHILOKYDES, ARISTAICHMOS)".

In this case DELPHIS, GNATHON, PHILOKYDES and ARISTAICHMOS are all names found only on this pot, and must be recorded as unique variables, even though they do not correspond to known mythological figures. The names of women are particularly difficult in this regard, as some are mythological characters and some appear to be names alone. It appears that painters used name inscriptions alongside morphologically similar figures, such as women, or in the example above, horsemen, much more than alongside gods with known attributes, as though anticipating the confusion that arises from trying to interpret scenes involving a number of seemingly identical characters.

The difficulty with these types of variables lies in the necessity of separating the names of known figures already identified by the scholar from those that are names alone. Furthermore, each name had to be examined in the context of its description in order to ensure that transcriptions of painted inscriptions were preserved while misspellings in the database were corrected. As an example, Athena is named in inscriptions as Athenaa, Athenaas, Athenaia, Athenaias, Athenais and Atheniai, but is also misspelled in one record as Athlena. This misspelling had to be corrected while the name inscriptions were left untouched. By following this laborious process we can be sure of getting an accurate count for each figure by not missing any due to errors in the data and not counting any twice due to their presence in descriptions and inscriptions.

To further complicate matters, the context of names given in inscriptions do not always match our expectations of those names. An example is Tragodia, whom we would naturally expect to find as a muse. However, the few occurrences of Tragodia as a name inscription all accompany what scholars have identified as Maenads, the female worshipers of Dionysus. Given the content of these scenes, it does not appear that the scholars are wrong, but rather that this particular name was more often associated with a maenad than a muse. In the one name inscription which accompanies a muse, the muse of tragedy is named Tragoidia, whose slightly different spelling may have been a signal to the audience that the painter was referring to the muse and not the maenad in this instance. The solution in this and all similar cases is to record all incidences of both names as unique variables. As will be seen, additional variables with a frequency of n=1 individually make almost no difference to the subsequent calculations. Therefore, as long as we remain within the broad limits of figure types, we risk nothing by adding additional low frequency names.

A few names used in inscriptions and descriptions were found to correspond to actual historical figures. There are less than 20 of these in the database, but those that are present were counted as unique variants. Those whose names can be matched up to known historical figures are primarily poets and athletes. Some kings who actually existed but whose lives were recorded primarily in myths are included in the mythological section above. As stated above, it is important to remember that these categories are not for analysis, they are only a helpful key for the grouping and identification of variants. Our goal was not to produce a complete key to every item in the description field of the database, but rather to produce a non-repeating list of unique variants. Whether a particular name is included as mythological or historical is irrelevant as long as it is only included once.

C. Roles

The contents of this category were based on things a figure could be described as "being". This was included in order to capture the "types" of non-mythological figures depicted. The following is a typical and not obviously mythological decoration description:

> WARRIORS SETTING OUT, ONE IN CHARIOT WITH CHARIOTEER, ARCHER, WOMAN

From this example we include the warrior, charioteer and archer but not the woman. Women, youths and men are the most numerous nouns used in descriptions in the database. These three terms alone appear 25,709 times. In contrast, the three most popular motifs from the three categories described above, satyrs, maenads and warriors, appear 10,625 times. We therefore decided that in order to observe meaningful patterns in the data, we would have to eliminate women, youths and men from the analysis. For consistency, all non-specific nouns, including women, men, youths, boys and children were not included. The roles these figures may have played, including warriors, athletes and participants in festivals and rituals (such as dancers and maenads), however, were included.

While these variables were included, several classes of description terms were not included. These are described below.

D. Scene Names

Scene names are used by pot scholars to indicate the general nature of a given scene, as in the following description:

> SYMPOSIUM, DIONYSOS RECLINING WITH VINE AND DRINKING HORN

Here, the scene name is Symposium, while the rest of the field describes what is taking place within that scene. While this formula is perfectly straightforward, Beazley and his followers did not always use it, so we often find that the above scene is described using the same terms but without the scene name of "symposium". Due to their inconsistent use, scene names were not included in the analysis.

E. Objects and animals

A vast array of objects are depicted on pots. These include weapons, clothing, food, architectural features, musical instruments and games. These are very interesting, but as our analysis of decoration focusses on the popularity of figures and types of figures, these objects were not included. Meta-depictions of pots (that is, pots being painted onto pots) also appear, but these are not included in our analysis. Only mythological animals (pegasoi, hydras, griffins) were included, while ordinary animals, such as dogs, cocks and cattle were not.

F. Decorative terms

There is an entire vocabulary devoted to the description of non-figurative painting, such as buds, palmettes, chevrons and meanders. As above, because our interest is in purely in the figurative elements of pots, these are not part of our analysis.

G. Adjectives, adverbs and verbs

These terms describe the actions of figures depicted on the pots. The 208 verbs in this list are especially amusing, as they describe all the different things the gods might have gotten up to, including everything from abducting to vomiting. As before, because we are interested in the figures themselves, and not their activities, we do not include these types of terms.

In all we created 23 different classifications of terms used in decorative descriptions. While we chose to analyse only figures, any of our other categories could also be used as the basis for future analysis.

Our final list contains 665 terms, which together appear a total of 38,681 times. At this point we had the database prepared, all spelling mistakes corrected and names normalised, and a list of terms ready to be counted. A special search program was written for this project by Laurence Tucker,  (Senior Software Engineer, BBC Future Media & Technology). This program allowed us to edit and re-create the database on our local system with ease. An additional program was written in Ruby which would search our database using SQL syntax. This program allowed us to create tables of results directly from our local database. It uses two additional files, one for the x axis and one for the y axis, as a search string, which could then be modified and enhanced with additional SQL syntax based on the requirements of each search. Using this system, each set of results could be as simple or as complex as required by the questions posed. For example, we might make one axis a list of shapes and the other a list of dates, with techniques, motifs, painters, provenances, or any combination thereof as an additional filter. The results would be made up of counts for all cells which matched each combination of each axis, plus the additional criteria.

However, further work had to be undertaken before counting could begin. There were two issues which needed to be resolved. The first was plural forms, and the second was terms appearing inside other terms. Plural forms were mostly straightforward. For example, to find all occurrences of satyrs, we searched for “Satyr”, which returned both “Satyr” (singular) and “Satyrs”. Whether there was only one satyr or many satyrs was not important for this analysis, we only asked whether satyrs were present. However, to look for “Pegasos” (singular) and “Pegosoi” (plural), we had to use a special syntax which searched for “Pegaso[is]”. This syntax tells the search script to return all occurrences of

“`Pegasoi`” or “Pegasos”. In some cases we searched only for part of the plural, as in “Harp[iy]”, which returns both “Harpy” and “Harpi”. Though the proper plural form is “Harpies”, the fact that “Harpi” only occurs within “Harpies” means that only the plural form of the term is returned, along with the singular. There were 12 search terms in our list of 665 which required this special fix.

The other problem faced in searching was the appearance of terms within other terms, for example “Hera” inside “Herakles” or “Ge” inside “Judge”. Using only a simple list, all counts for “Hera” would also include every occurrence of “Herakles”. In order to avoid this crucial problem we employed two tactics. First, we changed the the case of the decoration descriptions from all caps, as in the Beazley archive, to title case throughout (Every Word Capitalised). We then used the SQL search operator “GLOB” which is case sensitive, rather than “LIKE” which is not. This allowed us to search for “Ge” and not return any results for “Judge”. However, the problem remained of finding “Ge” within “Geryon”. To solve this, we created a separate query input, which used the “NOT GLOB” operator to find “Ge” but not “Geryon”. In the end, the search syntax for this query was as follows:

```
ruby new_selector_no_header.rb new_pottery_case_changed.db
conflicts/axis_final_conflicts_12 axis_ATHENIAN 'fabric="ATHENIAN" and
decoration NOT GLOB "*Geese*" and decoration NOT GLOB "*Genitals*" and
decoration NOT GLOB "*Geras*" and decoration NOT GLOB "*Geryon*"' >>
active_outputs/decorations_example.txt
```

In this example, we search for “Pan”:

```
ruby new_selector_no_header.rb new_pottery_case_changed.db
conflicts/axis_final_conflicts_25 axis_ATHENIAN 'fabric="ATHENIAN" and
decoration NOT GLOB "*Panathenaic*" and decoration NOT GLOB "*Pandaisia*"
and decoration NOT GLOB "*Pandion*" and decoration NOT GLOB "*Pandora*"
and decoration NOT GLOB "*Pandrosos*" and decoration NOT GLOB "*Panel*"
and decoration NOT GLOB "*Pankration*" and decoration NOT GLOB
"*Pankratists*" and decoration NOT GLOB "*Pannychis*" and decoration NOT
GLOB "*Panope*" and decoration NOT GLOB "*Pantariste*" and decoration NOT
GLOB "*Panther*" and decoration NOT GLOB "*Pantheress*" and decoration
NOT GLOB "*Panthers*" and decoration NOT GLOB "*Panyychis*"' >>
active_outputs/decorations_example.txt
```

In all, 36 conflicts were identified and resolved using the above process. While labour intensive and time consuming, these techniques were necessary to show that Ge, the personification of the earth, appeared only 14 times, rather than 65 times and Pan, the god of shepherds and flocks, appeared 46 times rather than 739 times. Once written, each search script could be modified and expanded to include other variables, as will be seen.

Our search script ran at a rate of around ten queries per second, as opposed to 1 query every five to ten minutes using the online Beazley archive by hand. Even if this had been feasible, the required complexity of the searches, as seen above, meant that a local copy had to be made in order to produce accurate results. Cleaning the Augean stables of the Beazley data was an additional bonus. Until a direct copy of the Beazley archive itself can be obtained (and then cleaned and organised all over again), these are the best possible results that can be generated.

### 3.4.2 Date categories

Decoration is not the only variable which is used in our analysis. Another crucial variable is date. There are 13 date categories in all, divided into 50 year groupings from 675 BC to 300 BC. The last set -400 to -300, is a 100 year group rather than 50 years. All date categories overlap adjacent categories by 25 years, which is an unavoidable feature of the way the dates were recorded by Beazley and his followers. Three categories, -400 to -350, -650 to -600 and -675 to -625, have only one representation each in the database and were therefore not included in the analysis. Our final list of dates is -625 to -575, -600 to -550, -575 to -525, -550 to -500, -525 to -475, -500 to -450, -475 to -425, -450 to -400, -425 to -375 and -400 to -300. There are 2,762 pots in our database with no value in the date field, while all of the remaining 39,056 pots fit into one of these ten categories. The Beazley archive presents all of these dates in two fields, start date and end date, but in order to speed up searches and simplify outputs we have combined them into a single new field containing both. Using this system the variables are also the data labels in the output text files, which saves a time consuming step of renaming in between. In the course of processing these fields, many mistakes were corrected, including the pot from 700 AD mentioned previously.

In no analysis do we perform any calculations based on the date itself, such as adding or subtracting dates or calculating the amount of time between pots. Date is always treated as a category only, and in our results we consider only the relative position of date ranges (early or late, before or after, and so on). Only in our concluding discussion, after the results, do we attempt to link Beazley's dates with known historical events.

### 3.4.3 Shapes

The pots in our database are divided between 130 shapes. These range from the plentiful lekythoi, which make up a very large proportion of the pots, to the very rare Oon, which is an an egg shaped object that appears only three times. It is simply not practical to count all 665 variables against each of 130 shapes. Furthermore, we can see little value in carrying out additional analyses to show the difference, for example, between motif frequencies on a Cup A as opposed to a Cup A Special Foot. We therefore decided to group the shapes into ten different categories. These are shown in table 3.1 below. On the left, we list the main term used in each shape description in the Beazley archive. Each input shape includes several subtypes, especially in cups, kraters and amphorae. On the right we show the group name given to each collection of shapes.[5]

All plastic figure vases, that is vases which are moulded into shapes, were moved to a separate database at this stage and we do not include them in any analysis. This is because despite there being more than 20 different types of plastic figure vase according to the Beazley classification, there are only 159 actual pots in our total figure vase sample, too few to analyse on their own.

| Input shapes | N | Group name |
|---|---|---|
| Pyxis | 449 | Pyxis |
| Lekanis | 270 | |
| Skyphos | 2069 | Skyphos |
| Kotyle | 3 | |
| Kantharos | 147 | |
| Mug | 112 | |
| Bowl | 5 | |
| Mastoid | 181 | |
| Chalice | 3 | |
| Cup | 7387 | Cups |
| Lekythos | 11642 | Lekythoi |
| Aryballos | 36 | |
| Alabastron | 424 | |
| Askos | 224 | |
| Plemochoe | 3 | |
| Lydion | 6 | |
| Plate | 335 | Plate |

| Input shapes | N | Group name |
|---|---|---|
| Nestoris | 1 | Ritual |
| Loutrophoros | 84 | |
| Lebes | 131 | |
| Phiale | 28 | |
| Amphora | 5409 | Amphora |
| Pelike | 1549 | |
| Stamnos | 400 | |
| Hydria | 1740 | Hydria |
| Oinochoe | 1967 | Oinochoe |
| Olpe | 473 | |
| Chous | 600 | |
| Kyathos | 218 | |
| Krater | 3150 | Krater |
| Dinos | 34 | |
| Psykter | 49 | |

Table 3.1. Shape categories

5 It is important to note that in all of the results and discussion which follows, the names of specific shapes are used in reference to these classifications, and not to the specific shape itself. One could, for example, replace "lekythoi" with "oil flask" or oinochoe with "wine-pourer", but it seemed more intuitively helpful to use the name of the vase with the highest frequency within each shape category, as it is these shapes which contribute most to the outcome of each test.

In order to make these groupings function in practice, we used the same complex SQL statements described above. For example, to search for pots in our cups category we used the following statement:

```
ruby new_selector_no_header.rb new_pottery_case_changed.db
conflicts/axis_final_conflicts_15 axis_2 'technique="BLACK-FIGURE" and
shape_record LIKE "%%Cup%%" and shape_record NOT GLOB "*Skyphos*" and
decoration NOT GLOB "*Herakles*" and decoration NOT GLOB "*Heraklles*"
and decoration NOT GLOB "*Herald*" and decoration NOT GLOB "*Heraldic*"
and decoration NOT GLOB "*Heraldic*"' >> active_outputs/BF_Cups.txt
```

This search returns a count of all cups decorated with Hera, using the black-figure technique. Note that we exclude skyphos from this count. This is to exclude the compound shape designation "cup skyphos", which is used 261 times in the Beazley archive. Without this specific exclusion, all results for "cup skyphos" would appear in the "cup" results in addition to the "skyphos" results. In the course of making the shape groupings many mistakes in shape names were corrected, including the shape designations "LEK CORINTH" and "LEK ERETRIA", which were changed to lekythoi. It appears in these cases when the data were entered into the Beazley archive, the shape code was combined with the provenance, for reasons unknown.

### 3.4.4 Techniques

All pots in our database were made using one of two techniques: black-figure and red-figure. We also found 8 pots with "black glaze", "black bodied" or "stamped" listed as their technique. These were removed from the database. A small proportion (4,421, or 10.5%) of the pots in the database are also listed with a value for sub-technique, such as silhouette, added colour or white ground. Each of these is a sub-type of one of the two main techniques. Given that so few pots used a sub-technique, we do not use this variable in the majority of our analyses. Instead we show results for the two main techniques and for a third sample of both techniques together. However, in chapter 6 we present a full set of results which examine sub-techniques in detail.

### 3.5 Data preparation complete

Having established the above methodology and made all the adjustments and corrections described, we are now able to produce accurate counts of any of the 4 main variables used in this study: motif, date, technique and shape, and in any combination.[6] In each analysis that follows, variables were combined in a search script, as described above, to produce tables of counts for each attribute being examined. In most cases, variables were combined in twos and threes, for example, `motif` x `shape` or `technique` x `shape` x `motif`, but in our main results we combine four variables: `technique` x `shape` x `date` x `motif`. This will tell us the frequency of each motif in each date category in each shape category, in black-figure, red-figure and both together. This analysis alone produces 219,450 individual unique results (3 techniques x 11 shapes (each category plus all together) x 10 dates x 665 motifs), and is only one of many that will be discussed in the following chapters.

As has been shown, every step of this study had to be re-invented from scratch. First we had to rebuild the data set of Athenian pottery from the ground up. Then we had to remove all the errors present in the data and organise the relevant fields. We then had to develop an original method for counting variables of interest in a variety of combinations. Then, in order to assess the fit of the neutral model to the data, we had to develop an original computer model which would output key parameters for comparison. Finally, we had to develop a method to compare these parameters over hundreds of samples. In the next chapter, we will describe the results of this work, and show where the neutral model

6 In addition to the variables described above, we also recorded and organised painter and provenance variables. There are 1,589 unique painters and groups in the database, which are attributed to a total of 31,116 pots (74% of the total), with the number of pots attributed to each painter ranging from 1 to over 1,000. Aside from removing data which were misplaced from other fields, we have not made any corrections to this field and have not changed any names given to painters. The provenance field describes where each pot was found. More than half (56%) of the pots in the database do not have a provenance. For the 18,390 pots which do have a provenance, there are a total of 1,038 unique descriptions. Some are specific down to the tomb or street in which the pot was found, while others specify only an entire country, such as Italy or Greece. Some use modern names, such as Bulgaria, some use ancient names, such as Thrace. In order to make it possible to analyse this field, we created a copy of the main database and eliminated all records which did not include a provenance description of some kind. We then added a new field to the database, the "provenance region", which is a general description of the area described by the provenance term itself. In all we created 26 categories and used a numeric code in the new `provenance region` field to indicate the region to which the original description referred. Using dictionaries and atlases to determine the best regional match for each description, we then manually coded all 1,038 provenance descriptions for all 18,390 pots. The result is that in our sub-database of provenances, all 18,390 pots each fit into one of 26 regional categories. Due to limits on the length of this thesis, we have not been able to include the resulting analysis, in which each of the 4 main variables were correlated with each painter and each provenance (as well as comparing painters and provenances with each other), but we hope to use this as the basis for future research into painter specialisation and the character of the export market.

can and cannot be rejected as an explanation for motif frequencies on Greek pottery. Following this, we provide contextualising comparisons of multiple parameters of pottery, in order to show where influences detected in the neutral results may have arisen. We will then show how all of these results together confirm or challenge existing ideas about figure-painted pottery.

# Chapter 4

# Results

In this chapter, we present the results of our tests of the neutral model for all 10 shape categories, as described in chapter 3, and an overall sample made up of all shapes. In each shape sample we describe the sample size, number of new motifs introduced, mutation rate, drift rate, theta and r-squared values and test results. After presenting these results individually, we will describe the overall findings and discuss the extent to which the neutral model can be used to describe variation in motifs in Greek figure-painted pottery.

## 4.1 Cups

### 4.1.1 Description

Cups are the among the most numerous of Athenian pottery shapes, their numbers surpassed in our sample only by lekythoi. Anywhere archaeologists find evidence of Greeks they also find a great quantity of cups. Therefore, whatever forces were at work in distributing decorative variants in Greek pottery should be especially pronounced in cups.

| sample | shapes | N |
|---|---|---|
| Cups | | |
| | Cup | 7128 |

Table 4.1.1. Sample size

Our sample of 7,128 cups includes numerous sub-types, none of which are significantly differentiated from one another in terms of decorative opportunities to warrant independent consideration. The only exception is the cup skyphos and its variants, which is considered separately. Though there is no evidence to suggest that the context in which a skyphos was used was any different from that of a cup, the skyphos shape is much deeper and more conical, and may have presented different decorative opportunities and constraints.

| | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|---|
| BF | 0 | 111 | 1083 | 1412 | 454 | 56 | 0 | 0 | 0 | 0 |
| RF | 0 | 1 | 4 | 27 | 941 | 1076 | 1260 | 436 | 51 | 216 |
| BF and RF | 0 | 112 | 1087 | 1439 | 1395 | 1132 | 1260 | 436 | 51 | 216 |

Table 4.1.2. Sample size over time.

Our sample of cups is distributed by date as shown in figure 4.1.1 and table 4.1.2 above. As with all of our samples, we consider black-figure (bf) and red-figure (rf) independently, as well as black-figure and red-figure (bf and rf) together in one sample. At each end of the joint black-figure and red-figure sample, the pots in the sample are the same as those covered in the independent black-figure or red-figure samples, as can be seen in the table above. It is still useful, however, to analyse the joint sample as a separate sample, as this gives us information about the dynamics of cups as a whole.

When black-figure and red-figure are considered together, cup production was high and relatively stable throughout the sample. When red-figure is introduced during the 525 to 475 date range, the overall total number of cups produced does not change a great deal, but black-figure rapidly diminishes to the point of complete disappearance by 475 BC. Such replacement is typical for most of our samples, though in some cases, such as amphorae, black-figure continues to be produced at a low level.

The overall distribution of pots shown in figure 4.1.1 is similar to the distribution found in other shape samples, with very few pots in the first two date ranges, followed by a high plateau and then a sharp drop in the 425 – 375 date category, which is then followed by a slight increase. We will discuss the possible causes for this pattern in the discussion which follows.

| | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|---|
| BF new | 0 | 11 | 66 | 20 | 14 | 0 | 0 | 0 | 0 | 0 |
| BF total | 0 | 11 | 74 | 63 | 50 | 13 | 0 | 0 | 0 | 0 |
| RF new | 0 | 0 | 0 | 2 | 48 | 43 | 18 | 18 | 0 | 0 |
| RF total | 0 | 0 | 1 | 12 | 93 | 112 | 78 | 65 | 10 | 27 |
| BF and RF new | 0 | 11 | 66 | 21 | 56 | 43 | 18 | 18 | 0 | 0 |
| BF and RF total | 0 | 11 | 74 | 65 | 109 | 112 | 78 | 65 | 10 | 27 |

Table 4.1.3. New and total motifs in the cups sample.

The number of motifs in use and the number of new motifs introduced during each time period are shown in figures 1.02 and 1.03 and table 4.1.3. As can be seen by comparing figure 4.1.2 with figure 4.1.1, the number of motifs in use tracks sample size, with the notable exception of the date category 550 – 500. During this period, we have 1,439 cups in our bf and rf sample, the highest for any single period. However, we have only 65 motifs in use in this sample, 11 fewer than the previous time period and 44 fewer than the subsequent time period. The greatest number of motifs in use during a single time period occurs within the 500 – 450 date category, with a sample size of 1,132. Of these, 95% are red-figure. As figure 4.1.1 shows, this period of greatest diversity corresponds with a dip in the overall sample size.

In addition to the number of motifs in use, we can also examine the number of motifs introduced, as shown in table 4.1.3 and figure 4.1.3. The greatest number of motifs introduced in a single time step was in the 575 - 525 date category, with 66 motifs introduced. The second greatest was in the 525 – 475 date category, with 56 motifs introduced. The first peak, during the 575 – 525 date category, was followed by a drop in the number of motifs in use, as described above, while the second peak in the 525 – 475 date category was followed by the period with the greatest number of motifs in use overall. In the first instance, the rise was caused by an increase in black-figure production, and in the second instance was caused by a rise in red-figure production. Why the red-figure increase was sustained but the black-figure rise was not will be discussed below.

| | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|
| BF mu | 0.10 | 0.06 | 0.01 | 0.03 | 0.00 | | | | |
| BF drift | 0.00 | 0.00 | 0.02 | 0.06 | 0.66 | | | | |
| RF mu | | | | 0.05 | 0.04 | 0.01 | 0.04 | 0.00 | 0.00 |
| RF drift | | | | -0.04 | 0.02 | 0.04 | 0.07 | 1.08 | -0.08 |
| BF and RF mu | 0.10 | 0.06 | 0.01 | 0.04 | 0.04 | 0.01 | 0.04 | 0.00 | 0.00 |
| BF and RF drift | 0.00 | 0.00 | 0.02 | 0.01 | 0.04 | 0.04 | 0.07 | 1.08 | -0.08 |

Table 4.1.4. Mutation and drift by technique and time period.

We can also interpret the number of motifs introduced as a mutation rate. The mutation rates for the cup sample are shown above in table 4.1.4 and figure 4.1.4. As described in chapter 2, these mutation rates represent the number of new motifs which appeared in each date category divided by the total number of pots present in the sample for that date category. Thus, given that 1076 red-figure cups were produced in the 500 - 450 date category (table 4.1.2, above) and 43 new motifs appeared (table 4.1.3, above), we have a mutation fraction of 0.04, or 4%.

Figure 4.1.4 shows that the innovation rate is extremely high in the early black-figure sample, but this is due to the statistical effect of having many new motifs and very few pots in the early portion of the sample. As described in chapter 2, each motif is counted as an innovation only once, and only in the technique in which it first appears. Therefore, if a motif is first used in black-figure, it is not counted as an innovation in any subsequent red-figure sample. The only exceptions to this rule are motifs which simultaneously appear in both red-figure and black-figure, which are counted in both techniques, but these are very rare and amount to 5 out of the 238 total motifs observed in this sample. In all samples, the first date category of 625 - 575 is not counted, as all motifs are new in the first time period.

The initial black-figure date categories of 600 - 550 and 575 - 525 had a very high rate of innovation. It is easy to discount this as being a side effect of the samples being early in the overall series, and being the time of first appearance for many motifs which would continue through all periods of both techniques. Given the data available, it is not possible to determine whether the 1% rate of innovation observed between 575 – 525 and 550 – 500 is more typical for early black-figure, as this is the only period before the introduction of red-figure for which the data are particularly strong. After this, when red-figure is introduced, innovation alternates between 1% and 4%, before dropping to 0 in the final two phases, when no new motifs are introduced in either technique. Despite the large number of motifs introduced in the 525 – 475 date category, the transitional periods between black-figure and red-figure shows a mutation rate of 4%, which is greater than the previous phase, but not exceptional when compared with subsequent phases.

Rates of drift are also shown in table 4.1.4 and in figures 1.05, 1.06 and 1.07. Drift, as described in chapter 2, is defined for our purposes as the proportion of motifs not copied from one time period to the next. Rates of drift are very high for the terminal stages of both techniques, but are well balanced with mutation during the periods of normal production. The very high rate of drift (66%) shown in the date category 500 - 450 indicates that during this phase, two thirds of all motifs which were present in black-figure in the previous time step were not copied. Negative drift can also occur, as in the date category 400 - 300 in red-figure. During this period -8% of the motifs present in the previous time step were not copied. Once the double negatives in this statement are unpacked, we see that it actually means there was an 8% gain in the number of motifs present, but that these were not present in the previous time step, instead being copied from a time step further back, as described in chapter 2. The periods with these strange drift results are periods during which production in the given technique was drastically reduced, and which we would therefore expect to be subject to a form of non-neutral bias. In the remaining samples, our cups are generally at equilibrium, as figures 1.05 to 1.07 show. Equilibrium is defined as a balance in the rate of innovation and drift, and is the starting point for tests of the neutral hypothesis.

### 4.1.2 Estimates of theta

Testing how well our data fit the neutral model is carried out through comparison with a model, as described above. For each date category with a sample size of 50 pots or more, theta was computed in two ways: as a measure of diversity based on the frequency of motifs in the sample (tF) and the expected diversity under the neutral model for the given sample size and number of unique motifs (tE). In samples which do not deviate from the predictions of the neutral model, larger samples should contain more diversity.

The results of our calculations of tE and tF for each sample are shown in figures 1.08, 1.09 and 1.10 and table 4.1.5 below. We can see that the pattern of rising and falling diversity shown in the figures is very similar to the pattern of rising and falling innovation and sample size shown in figures 1.01 and 1.04. When the number of pots produced is high, diversity is high, and when it is low, diversity is also low. The only exception to this is the early black-figure sample shown in figure 4.1.8, which shows far higher tF than tE in the early phases. This tells us that there are more motifs at higher frequency present in these samples than the sample size would predict, indicating that the diversity of the low-N samples is greater than expected by the neutral model. This is a pattern we will see repeated throughout the samples in this study, and is caused by the large number of motifs which appear for the first time during these periods.

| | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|---|
| BF tE | | 3.208 | 18.142 | 13.660 | 14.534 | 5.608 | | | | |
| BF tF | | 38.490 | 32.315 | 24.146 | 7.600 | 14.525 | | | | |
| RF tE | | | | 8.831 | 25.798 | 31.634 | 18.539 | 21.373 | 3.976 | 8.347 |
| RF tF | | | | 16.780 | 16.354 | 30.722 | 34.636 | 13.956 | 10.458 | 9.735 |
| BF and RF tE | | 3.197 | 18.121 | 14.136 | 27.829 | 31.044 | 18.539 | 21.373 | 3.976 | 8.347 |
| BF and RF tF | | 39.205 | 32.481 | 24.380 | 15.060 | 31.125 | 34.636 | 13.956 | 10.458 | 9.735 |

Table 4.1.5. Estimates of theta.

Having established the above measures of theta, we can now proceed to test them for adherence to the neutral model by comparing them with the results of our simulation. To test for the difference between our model and data, we do not compare each individual measure of theta, but rather we compare the unsigned difference between each measure of theta, as described above. The results of this comparison for our cups sample are shown in figure 4.1.10 and table 4.1.7.

Table 4.1.6 shows the results of a comparison between the |tf-te| value for each sample in our data at differing thresholds of significance. At the 1% level, we compare the lowest 1% of values from our model with the values from our data. If the values from the data are less than those found in the model, then we conclude that the theta difference found in our data is less than the difference found in the lowest 1% of values in our model, and are therefore unable to reject the neutral model at the 1% level of significance.

We repeat the process for 5% and 10%. 10% is a lower level of significance than we would expect for tests of this nature, but is included to show how the outcomes change at different levels of significance. The diversity of each phase of the data is compared with the results of the simulation for the closest tenth of a percent of mutation and closest hundred of population. As described above, samples with N>1000 are compared to the nearest 1000. Samples which show mutation levels of mu<0.01, such as the 425 - 375 and 400 – 300 date categories are compared with the nearest N at mu=0.001.

| CUPS | SAMPLE | N | mu | 1% | 5% | 10% | tf-te at 5% level |
|---|---|---|---|---|---|---|---|
| BF | 600 - 550 | 111 | 0.10 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| BF | 575 - 525 | 1083 | 0.06 | ACCEPT | ACCEPT | ACCEPT | |
| BF | 550 - 500 | 1412 | 0.01 | ACCEPT | **REJECT** | **REJECT** | more diverse |
| BF | 525 - 475 | 454 | 0.03 | ACCEPT | ACCEPT | ACCEPT | |
| BF | 500 - 450 | 56 | 0.00 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| RF | 525 - 475 | 941 | 0.05 | ACCEPT | ACCEPT | ACCEPT | |
| RF | 500 - 450 | 1076 | 0.04 | ACCEPT | ACCEPT | ACCEPT | |
| RF | 475 - 425 | 1260 | 0.01 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| RF | 450 - 400 | 436 | 0.04 | ACCEPT | ACCEPT | ACCEPT | |
| RF | 425 - 375 | 51 | 0.00 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| RF | 400 - 300 | 216 | 0.00 | ACCEPT | **REJECT** | **REJECT** | more diverse |
| BF AND RF | 600 - 550 | 112 | 0.10 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| BF AND RF | 575 - 525 | 1087 | 0.06 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 550 - 500 | 1439 | 0.01 | ACCEPT | **REJECT** | **REJECT** | more diverse |
| BF AND RF | 525 - 475 | 1395 | 0.04 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 500 - 450 | 1132 | 0.04 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 475 - 425 | 1260 | 0.01 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| BF AND RF | 450 - 400 | 436 | 0.04 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 425 - 375 | 51 | 0.00 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| BF AND RF | 400 - 300 | 216 | 0.00 | ACCEPT | **REJECT** | **REJECT** | more diverse |

Table 4.1.6. Comparison of |tf-te| for model and data.

The results in table 4.1.6 show that at the 5% significance level, 6 out of the 11 individual technique samples reject the neutral model, while in the joint black-figure and red-figure sample, 5 out 9 samples reject the neutral model. All cup samples which are rejected by the neutral model are more diverse than expected for their given levels of N and mu, as calculated by a comparison between our model values and the signed difference in theta estimates. Interestingly, in neither black-figure nor red-figure is the date category 525 - 475 rejected by the neutral model, which is unexpected as this period is often described as one in which painters were actively biased towards innovation. The following date category 500 - 450, in which red-figure properly replaced black-figure as the preferred medium for figure painting on cups, shows greater than neutral levels of diversity only in the tiny remnant of the black-figure sample, but not in red-figure, which remains in accordance with the neutral model. We will discuss the reasons for these particular phases being non-neutral in greater detail below.

### 4.1.3 Power law distributions

In the above section we examined whether the diversity in the frequency distribution of motifs in our sample matches the level of diversity expected for a given number of pots under the neutral model. In addition to this analysis, we can also determine whether the frequency distribution of the individual motifs in our sample matches the expected distribution of motifs in a neutral system in which drift and innovation are balanced. This is done by examining the frequencies of motifs in our sample and their fit to a power law, which Bentley *et. al.* (2004) have shown to be the signature of a neutral model distribution. The frequencies of the motifs are found by counting the number of motifs that appear 1 time, 2 times, 4 times and so on by powers of 2, and then calculating these binned frequencies as a probability relative to the total number of motifs observed. Under the neutral model we expect to find many motifs that appear only a few times and a few motifs used many times, with a linear distribution of motifs in between.

| | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|
| BF | 0.837 | 0.955 | 0.983 | 0.956 | 0.915 | | | | |
| RF | | | | 0.972 | 0.951 | 0.994 | 0.932 | 0.789 | 0.961 |
| BF and RF | 0.837 | 0.955 | 0.986 | 0.990 | 0.938 | 0.994 | 0.932 | 0.789 | 0.961 |

Table 4.1.7. R-squared values.

We calculated the r-squared value of the frequency distribution of motifs for each date category in our sample. The r-squared value represents the degree to which changes in the probability of a motif appearing can be explained by changes in its frequency. As can be seen in table 4.1.7 and figure 4.1.12, the r-squared values for each sample are very high. In each date category under examination nearly all (between 93.2% and 99.4%) of the changes in probability can be explained by changes in frequency.

These r-squared values can be compared with the results of the model using the same methods described above, with the difference that here we are looking for lower r-squared values in our data than in the model in order to reject the neutral model. The results of this comparison can be seen in figure 4.1.13 and table 4.1.8 below.

| CUPS | SAMPLE | N | mu | 1% | 5% | 10% |
|---|---|---|---|---|---|---|
| BF | 600 - 550 | 111 | 0.10 | ACCEPT | **REJECT** | **REJECT** |
| BF | 575 - 525 | 1083 | 0.06 | ACCEPT | ACCEPT | ACCEPT |
| BF | 550 - 500 | 1412 | 0.01 | ACCEPT | ACCEPT | ACCEPT |
| BF | 525 - 475 | 454 | 0.03 | ACCEPT | ACCEPT | ACCEPT |
| BF | 500 - 450 | 56 | 0.00 | ACCEPT | ACCEPT | ACCEPT |
| RF | 525 - 475 | 941 | 0.05 | ACCEPT | ACCEPT | ACCEPT |
| RF | 500 - 450 | 1076 | 0.04 | ACCEPT | ACCEPT | ACCEPT |
| RF | 475 - 425 | 1260 | 0.01 | ACCEPT | ACCEPT | ACCEPT |
| RF | 450 - 400 | 436 | 0.04 | ACCEPT | ACCEPT | **REJECT** |
| RF | 425 - 375 | 51 | 0.00 | ACCEPT | ACCEPT | ACCEPT |
| RF | 400 - 300 | 216 | 0.00 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 600 - 550 | 112 | 0.10 | ACCEPT | **REJECT** | **REJECT** |
| BF AND RF | 575 - 525 | 1087 | 0.06 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 550 - 500 | 1439 | 0.01 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 525 - 475 | 1395 | 0.04 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 500 - 450 | 1132 | 0.04 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 475 - 425 | 1260 | 0.01 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 450 - 400 | 436 | 0.04 | ACCEPT | ACCEPT | **REJECT** |
| BF AND RF | 425 - 375 | 51 | 0.00 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 400 - 300 | 216 | 0.00 | ACCEPT | ACCEPT | ACCEPT |

Table 4.1.8. R-squared values, model and data comparison

As can be seen from these results, the power law test is extremely forgiving. At the 5% level, only the first period (600 to 550) of black-figure cups and its corresponding sample in the combined sample, rejects the neutral model. All other samples fail to reject the neutral model, and using this test cannot be shown to be not neutral. We therefore conclude that this is a weak test, but also note that all samples with the exception of early black-figure are within the predictions of the neutral model. This result corresponds with the results of our theta analysis above, which also showed that the first period of black-figure cups is not neutral and shows signs of being more diverse than expected.

| CUPS RESULTS | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| sample | test | 600-550 | 575-525 | 550-500 | 525-475 | 500-450 | 475-425 | 450-400 | 425-375 | 400-300 |
| BF | R-squared | **X** | **0** | **0** | **0** | **0** | | | | |
| | Theta | **>** | **0** | **>** | **0** | **>** | | | | |
| RF | R-squared | | | | **0** | **0** | **0** | **0** | **0** | **0** |
| | Theta | | | | **0** | **0** | **>** | **0** | **>** | **0** |
| BF and RF | R-squared | **X** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** |
| | Theta | **>** | **0** | **>** | **0** | **0** | **>** | **0** | **>** | **>** |

**0** = neutral model not rejected **X** = neutral model rejected by 5% r-squared test

**>** = more diverse at 5% theta test **<** = less diverse at 5% theta test

Table 4.1.9. Summary of results.

## 4.2 Skyphos

### 4.2.1 Description

The skyphos was a form of drinking cup. While the more popular standard cups were wide and shallow, the skyphos was deeper. Sometimes these were flat at the bottom and sometimes they would be pointed, as in the mastoid shape. The depth of these cups made decoration with figures around the sides much more prominent than in standard cups, which is why they are considered separately.

| sample | shapes | N |
|---|---|---|
| Skyphos | | |
| | Skyphos | 2069 |
| | Kotyle | 3 |
| | Kantharos | 147 |
| | Mug | 112 |
| | Bowl | 5 |
| | Mastoid | 181 |
| | Chalice | 3 |

Table 4.2.1. Sample size.

As with the numerous subtypes of standard cups, the few subtypes of skyphos shape, or closely related shapes, are not sufficiently different from the skyphos itself to warrant independent examination. It should also be noted that the final usable total of 2,334 skyphoi is slightly less than the total given above. This is due to records which were found to be incomplete or whose descriptions did not include any of the motifs being considered in this stage of the study.

| | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 -375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|---|
| BF | 5 | 50 | 52 | 447 | 687 | 114 | 1 | 0 | 1 | 1 |
| RF | 0 | 0 | 1 | 1 | 61 | 99 | 396 | 229 | 60 | 134 |
| BF and RF | 5 | 50 | 53 | 448 | 748 | 213 | 397 | 229 | 61 | 135 |

Table 4.2.2. Sample size over time.

The number of pots in the skyphos sample is shown in table 4.2.2 and figure 4.2.1. While the cup sample showed relative continuity of production over time, the production of the skyphos shape noticeably peaks twice: once in the black-figure 525 - 475 date category and later in the red-figure 475 - 425 date category. The skyphos is found in greater numbers in black-figure than in red-figure. However, as in cups, once the red-figure technique is introduced it almost completely replaces black-figure.

Table 4.2.3 and figure 4.2.2 show the number of motifs in use in the skyphos sample. As expected, more motifs are in use in the samples containing greater numbers of pots. Large samples in the 525 - 475 and 475 - 425 date categories are also matched by the introduction of many new motifs (figure 4.2.3). When sample size shrinks in the 425 - 375 and 400 – 300 date categories, the number of new motifs and the number of total motifs in use are greatly reduced.

| | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|---|
| BF new | 2 | 3 | 12 | 28 | 30 | 1 | 0 | 0 | 0 | 0 |
| BF total | 2 | 5 | 15 | 43 | 60 | 21 | 0 | 0 | 1 | 2 |
| RF new | 0 | 0 | 0 | 0 | 6 | 14 | 17 | 28 | 1 | 4 |
| RF total | 0 | 0 | 0 | 1 | 19 | 32 | 51 | 59 | 13 | 24 |
| BF and RF new | 2 | 3 | 12 | 28 | 33 | 15 | 17 | 28 | 1 | 4 |
| BF and RF total | 2 | 5 | 15 | 43 | 66 | 44 | 51 | 59 | 13 | 24 |

Table 4.2.3. New and total motifs.

| | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 -375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|
| BF mu | 0.06 | 0.23 | 0.06 | 0.04 | 0.01 | | | | |
| BF drift | 0.00 | 0.04 | 0.00 | 0.02 | 0.35 | | | | |
| RF mu | | | | 0.10 | 0.14 | 0.04 | 0.12 | 0.02 | 0.03 |
| RF drift | | | | -0.20 | 0.01 | -0.01 | 0.09 | 0.78 | -0.05 |
| BF and RF mu | 0.06 | 0.23 | 0.06 | 0.04 | 0.07 | 0.04 | 0.12 | 0.02 | 0.03 |
| BF and RF drift | -0.04 | 0.04 | 0.00 | 0.01 | 0.17 | 0.03 | 0.09 | 0.77 | -0.05 |

Table 4.2.4. Mutation and drift by technique and time period.

The mutation rate of the skyphos sample is shown above in table 4.2.4 and figure 4.2.4. As in many of the shape samples, the first two black-figure date ranges show very high levels of innovation, due to very small sample size relative to the number of motifs and the first appearance of many motifs used throughout each sample. As in the cups sample, innovation rates for red-figure appear to be very high during the 525 - 475 date category. However, in the combined BF and RF sample, this spike flattens out into a rate consistent with the surrounding date categories (figure 4.2.4). The most noticeable rise in innovation in later skyphoi was during the 450 - 400 date category, with the number of pots bearing a new motif reaching over 10%.

Figure 4.2.4 and figures 4.2.5, 4.2.6 and 4.2.7 also show the rate of drift, that is, the number of motifs not copied from the previous time step. Drift and mutation rates in black-figure are close together in the 525 - 475 and 550 – 500 date categories, but far apart in previous time steps due to the effects of many motifs appearing for the first time early in the sample. At the end of black-figure skyphos production in the 500 – 450 date category, drift shoots up, as nearly all motifs fail to be copied. In red-figure (figure 4.2.6), we see that for most of the sample drift and innovation are well balanced, with the notable exception of the 425 – 375 date category , when 78% of motifs were not copied from the previous time step. This is due to the vast reduction in sample size during this period, from 229 in the previous time step to only 60 in the 425 - 375 date category. We see a similar reduction in many shapes in their 425 – 375 date category, and will consider possible explanations for it in the discussion which follows. For now, we predict that this period will reject the neutral model in red-figure as well as in the joint black-figure and red-figure sample. The final date category, 400 - 300, shows a return to near equilibrium.

### 4.2.2 Estimates of theta

The results of our calculation of tE and tF for the skyphos sample are shown below in table 4.2.5 and in figures 4.2.8, 4.2.9 and 4.2.10. As can be seen from these results, tE and tF do not track each other throughout each sample. In black-figure, they converge only in the 525 – 475 date category, while in red-figure they converge only in the first and last samples.

When we compare the tE and tF results of our data with the model (table 4.2.6), we see that the neutral model is not rejected at the 5% level during the date ranges in which tE and tF are close together, for all samples. The date categories in which drift far exceeded mutation reject the neutral model (500 - 450 BF and 425 - 375 RF and BF/RF), as expected.

| | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|---|
| BF tE | | 1.551 | 7.411 | 11.907 | 15.985 | 7.812 | | | | |
| BF tF | | 12.298 | 26.876 | 17.754 | 15.713 | 18.902 | | | | |
| RF tE | | | | | 9.839 | 16.791 | 15.782 | 26.060 | 5.385 | 8.766 |
| RF tF | | | | | 10.208 | 55.006 | 48.174 | 32.920 | 30.579 | 10.408 |
| BF and RF tE | | 1.551 | 7.312 | 11.897 | 17.630 | 17.105 | 15.766 | 26.060 | 5.334 | 8.733 |
| BF and RF tF | | 12.298 | 27.959 | 17.599 | 16.982 | 35.295 | 48.423 | 32.920 | 29.752 | 10.535 |

Table 4.2.5. Estimates of theta.

| SKYPHOS | SAMPLE | N | mu | 1% | 5% | 10% | tf-te at 5% level |
|---|---|---|---|---|---|---|---|
| BF | 600 - 550 | 50 | 0.06 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| BF | 575 - 525 | 52 | 0.23 | ACCEPT | ACCEPT | ACCEPT | |
| BF | 550 - 500 | 447 | 0.06 | ACCEPT | ACCEPT | ACCEPT | |
| BF | 525 - 475 | 687 | 0.04 | ACCEPT | ACCEPT | ACCEPT | |
| BF | 500 - 450 | 114 | 0.01 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| RF | 525 - 475 | 61 | 0.10 | ACCEPT | ACCEPT | ACCEPT | |
| RF | 500 - 450 | 99 | 0.14 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| RF | 475 - 425 | 396 | 0.04 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| RF | 450 - 400 | 229 | 0.12 | ACCEPT | ACCEPT | ACCEPT | |
| RF | 425 - 375 | 60 | 0.02 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| RF | 400 - 300 | 134 | 0.03 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 600 - 550 | 50 | 0.06 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| BF AND RF | 575 - 525 | 53 | 0.23 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 550 - 500 | 448 | 0.06 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 525 - 475 | 748 | 0.04 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 500 - 450 | 213 | 0.07 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| BF AND RF | 475 - 425 | 397 | 0.04 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| BF AND RF | 450 - 400 | 229 | 0.12 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 425 - 375 | 61 | 0.02 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| BF AND RF | 400 - 300 | 135 | 0.03 | ACCEPT | ACCEPT | ACCEPT | |

Table 4.2.6. Comparison of |tf-te| for model and data.

In the samples which reject the neutral model, they do so in the direction of increased diversity. As in the cups sample, this means that in these date ranges there are more motifs at high frequency than would be expected under the neutral model for the given sample size and level of mutation. It is interesting to note that as in cups, the date category 525 - 475 does not reject the neutral model in any of the three technique samples, but in the 500 – 450 date category, in which red-figure fully replaces black-figure as the preferred medium for skyphoi, we see greater than neutral levels of diversity. This means that the same motifs were used many times over in the new technique.

### 4.2.3 Power law distributions

As in our cups sample, we can also examine the dynamics of each shape sample by fitting each to a power law and calculating the r-squared value. As described in chapter 2, the higher the r-squared value, the better the fit and the more closely the data correspond to the distribution predicted by the neutral model.

| | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|
| BF | 0.995 | 0.637 | 0.970 | 0.970 | 0.919 | | | | |
| RF | | | | 0.933 | 0.872 | 0.973 | 0.801 | 0.815 | 0.931 |
| BF and RF | 0.995 | 0.637 | 0.970 | 0.978 | 0.977 | 0.973 | 0.801 | 0.815 | 0.979 |

Table 4.2.7. R-squared values.

| SKYPHOS | SAMPLE | N | mu | 1% | 5% | 10% |
|---|---|---|---|---|---|---|
| BF | 600 - 550 | 50 | 0.06 | ACCEPT | ACCEPT | ACCEPT |
| BF | 575 - 525 | 52 | 0.23 | **REJECT** | **REJECT** | **REJECT** |
| BF | 550 - 500 | 447 | 0.06 | ACCEPT | ACCEPT | ACCEPT |
| BF | 525 - 475 | 687 | 0.04 | ACCEPT | ACCEPT | ACCEPT |
| BF | 500 - 450 | 114 | 0.01 | ACCEPT | ACCEPT | ACCEPT |
| RF | 525 - 475 | 61 | 0.10 | ACCEPT | ACCEPT | ACCEPT |
| RF | 500 - 450 | 99 | 0.14 | ACCEPT | **REJECT** | **REJECT** |
| RF | 475 - 425 | 396 | 0.04 | ACCEPT | ACCEPT | ACCEPT |
| RF | 450 - 400 | 229 | 0.12 | **REJECT** | **REJECT** | **REJECT** |
| RF | 425 - 375 | 60 | 0.02 | ACCEPT | ACCEPT | ACCEPT |
| RF | 400 - 300 | 134 | 0.03 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 600 - 550 | 50 | 0.06 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 575 - 525 | 53 | 0.23 | **REJECT** | **REJECT** | **REJECT** |
| BF AND RF | 550 - 500 | 448 | 0.06 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 525 - 475 | 748 | 0.04 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 500 - 450 | 213 | 0.07 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 475 - 425 | 397 | 0.04 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 450 - 400 | 229 | 0.12 | **REJECT** | **REJECT** | **REJECT** |
| BF AND RF | 425 - 375 | 61 | 0.02 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 400 - 300 | 135 | 0.03 | ACCEPT | ACCEPT | ACCEPT |

Table 4.2.8. R-squared values, model and data comparison

As can be seen from the results shown in table 4.2.7 above, the r-squared values for the black-figure skyphoi are quite high, as are the overlapping black-figure and red-figure samples. Of the larger samples, it is the red-figure sample alone which shows a much poorer fit, with 87% and 80% fit for the 500 - 450 and 450 - 400 date categories. When we compare these results with r-squared values for the model, shown in table 4.2.8, we see that these low values are even lower than those produced by the model at the 5% level of significance. However, the majority of skyphos samples do not reject the neutral model using this analysis.

| SKYPHOS RESULTS | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| sample | test | 600-550 | 575-525 | 550-500 | 525-475 | 500-450 | 475-425 | 450-400 | 425-375 | 400-300 |
| BF | R-squared | **0** | **X** | **0** | **0** | **0** | | | | |
| | Theta | **>** | **0** | **0** | **0** | **>** | | | | |
| RF | R-squared | | | | **0** | **X** | **0** | **X** | **0** | **0** |
| | Theta | | | | **0** | **>** | **>** | **0** | **>** | **0** |
| BF and RF | R-squared | **0** | **X** | **0** | **0** | **0** | **0** | **X** | **0** | **0** |
| | Theta | **>** | **0** | **0** | **0** | **>** | **>** | **0** | **>** | **0** |

**0** = neutral model not rejected **X** = neutral model rejected by 5% r-squared test

**>** = more diverse at 5% theta test **<** = less diverse at 5% theta test

Table 4.2.9. Summary of results.

## 4.3 Oinochoe

### 4.3.1 Description

Greek potters produced a number of shapes designed for pouring wine. These were used to transfer the contents of kraters into the cups we have discussed above and other vessels. Alongside cups and kraters, an oinochoe was an essential element of the symposium.

| sample | shapes | N |
|---|---|---|
| Oinochoe | | |
| | Oinochoe | 1967 |
| | Olpe | 473 |
| | Chous | 600 |
| | Kyathos | 218 |

Table 4.3.1. Sample size

The oinochoe sample includes the above shapes. These shapes tended to be tall and narrow, often with a handle on one side and a wide opening at the top. The kyathos is almost a cup, having the shortest body of the four listed here, but given its apparent function as a dipper it is included with the other shapes used for pouring wine. On these shapes the figured scenes are arranged as a panelled picture, with the action taking place between horizontal decorative bands.

| | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|---|
| BF | 12 | 62 | 49 | 600 | 1010 | 50 | 3 | 2 | 25 | 1 |
| RF | 0 | 0 | 0 | 5 | 16 | 96 | 202 | 528 | 248 | 349 |
| BF and RF | 12 | 62 | 49 | 605 | 1026 | 146 | 205 | 530 | 273 | 350 |

Table 4.3.2. Sample size over time.

The oinochoe sample is distributed by date as shown in table 4.3.2 above and figure 4.3.1. As can be seen, oinochoe occur in greater numbers in the sixth century than in the fifth, and consequently more are found in black-figure than in red-figure. Like the skyphos, the peak of production was during the 525 - 475 date category, followed by near total replacement by a smaller quantity of red-figure versions. While the cup sample showed relative continuity in overall sample size, the skyphos and oinochoe samples show two distinct peaks of production. There are two corresponding peaks in the number of motifs in use and in the numbers of new motifs introduced, as shown in figures 4.3.2 and 4.3.3, and table 4.3.3 below.

The mutation rate of the oinochoe sample is shown below in table 4.3.4 and in figure 4.3.4. As with many of the samples, there is an artificially high mutation rate in the first two black-figure samples, which then settles down to a more stable rate. As described above, this is due to the large number of new motifs which appear for the first time in the 575 – 525 date category. For example, there are only 49 pots in the 575 - 525 date category, yet 21 new motifs appear, giving a mutation fraction approaching 50%. The spike in innovation at the beginning of red-figure appears for the same reason. In the 525 - 475 date category red-figure sample, there are only 16 pots which carry 3 previously unseen motifs (table 4.3.3), resulting in a mutation rate of 19%. The effect of these 3 motifs is less dramatic when the 1010 black-figure pots from the same period are added to form the joint BF and RF sample. With a total of 38 new motifs for this sample, the period then shows only a 4% mutation rate. This rises to 10% in the subsequent periods, before ebbing away at the end, along with all figure-painted pottery production.

| | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|---|
| BF new | 2 | 7 | 21 | 55 | 37 | 1 | 0 | 0 | 0 | 0 |
| BF total | 2 | 9 | 26 | 78 | 101 | 21 | 0 | 0 | 4 | 1 |
| RF new | 0 | 0 | 0 | 5 | 3 | 14 | 20 | 24 | 8 | 7 |
| RF total | 0 | 0 | 0 | 7 | 18 | 31 | 62 | 75 | 31 | 31 |
| BF and RF new | 2 | 7 | 21 | 58 | 38 | 15 | 20 | 24 | 8 | 7 |
| BF and RF total | 2 | 9 | 26 | 81 | 102 | 43 | 62 | 75 | 31 | 31 |

Table 4.3.3. New and total motifs.

| | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|
| BF mu | 0.11 | 0.43 | 0.09 | 0.04 | 0.02 | | | | |
| BF drift | 0.00 | 0.08 | 0.01 | 0.01 | 1.62 | | | | |
| RF mu | | | | | 0.15 | 0.10 | 0.05 | 0.03 | 0.02 |
| RF drift | | | | | 0.01 | -0.05 | 0.02 | 0.21 | 0.02 |
| BF and RF mu | 0.11 | 0.43 | 0.10 | 0.04 | 0.10 | 0.10 | 0.05 | 0.03 | 0.02 |
| BF and RF drift | 0.00 | 0.08 | 0.00 | 0.02 | 0.51 | 0.00 | 0.02 | 0.19 | 0.02 |

Table 4.3.4. Mutation and drift by technique and time period.

Rates of drift and mutation are shown in table 4.3.4 and figures 4.3.5, 4.3.6 and 4.3.7. In black-figure (figure 4.3.5), we see that after the initial periods of high mutation, mutation and drift are similar, until the 500 – 450 date category, in which nearly all black-figure motifs fail to be copied. The drift rate of 162% is due to the tiny sample size (n=50) compared to the previous sample (n=1010). In red-figure, we see low rates of drift in the first two periods (even a negative rate, in which more motifs are added than were not copied from the previous time step). In 450 – 400 rates of drift and mutation almost reach equilibrium, but this is followed by a period of high drift in the 425 – 375 category, in which many motifs were not copied. The extremely high rate of drift in the 425 - 375 date category is seen in other shapes, and is in this case, as in others, due to a reduction of the sample size by more than half. Drift is reduced in the combined 425 – 375 sample (figure 4.3.7), but is still high.

### 4.3.2 Estimates of theta

The results of our calculations of theta are shown below in table 4.3.5. The black-figure sample includes data for the 425 - 375 date category, but not for the intervening date categories of 475 - 425 and 450 - 400. This is due to the lack of sufficient data for these periods. As will be seen in other results below, there are often isolated periods of black-figure pottery late in each sample. This is because black-figure production never fully stops, even after the ascendancy of red-figure, but continues at a very low level. In many samples the quantities are too small to measure (N<20), but here there were just enough. We were unable, however, to run our model against this sample, as the n=50 is the minimum value for a reliable test.

| | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|---|
| BF tE | | 3.106 | 23.194 | 24.123 | 28.123 | 14.145 | | | 1.559 | |
| BF tF | | 13.451 | 7.454 | 5.764 | 4.091 | 6.440 | | | 19.833 | |
| RF tE | | | | | | 16.266 | 30.915 | 24.102 | 9.554 | 8.390 |
| RF tF | | | | | | 23.381 | 17.726 | 63.118 | 37.779 | 3.873 |
| BF and RF tE | | 3.106 | 23.194 | 25.356 | 28.338 | 20.910 | 30.578 | 24.063 | 9.192 | 8.382 |
| BF and RF tF | | 13.451 | 7.454 | 5.817 | 4.203 | 15.422 | 18.286 | 63.604 | 37.858 | 3.893 |

Table 4.3.5. Estimates of theta.

| OINOCHOE | SAMPLE | N | mu | 1% | 5% | 10% | tf-te at 5% level |
|---|---|---|---|---|---|---|---|
| BF | 600 - 550 | 62 | 0.11 | ACCEPT | ACCEPT | ACCEPT | |
| BF | 550 - 500 | 600 | 0.09 | ACCEPT | ACCEPT | ACCEPT | |
| BF | 525 - 475 | 1010 | 0.04 | ACCEPT | **REJECT** | **REJECT** | less diverse |
| BF | 500 - 450 | 50 | 0.02 | **REJECT** | **REJECT** | **REJECT** | less diverse |
| RF | 500 - 450 | 96 | 0.15 | ACCEPT | ACCEPT | ACCEPT | |
| RF | 475 - 425 | 202 | 0.10 | ACCEPT | ACCEPT | ACCEPT | |
| RF | 450 - 400 | 528 | 0.05 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| RF | 425 - 375 | 248 | 0.03 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| RF | 400 - 300 | 349 | 0.02 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 600 - 550 | 62 | 0.11 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 550 - 500 | 605 | 0.10 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 525 - 475 | 1026 | 0.04 | ACCEPT | **REJECT** | **REJECT** | less diverse |
| BF AND RF | 500 - 450 | 146 | 0.10 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 475 - 425 | 205 | 0.10 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 450 - 400 | 530 | 0.05 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| BF AND RF | 425 - 375 | 273 | 0.03 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| BF AND RF | 400 - 300 | 350 | 0.02 | ACCEPT | ACCEPT | ACCEPT | |

Table 4.3.6. Comparison of |tf-te| for model and data.

The results of the model are compared with the results for the oinochoe samples in table 4.3.6 above. The black-figure sample begins neutral but then becomes non neutral as sample size increases from N=600 in the 550 – 500 date category to N=1010 in the 525 –

475 date category. The direction of non-neutrality is both less diverse than expected in black-figure and more diverse than expected in red-figure. This indicates that there were fewer than expected motifs at high frequencies in black-figure, and more at high frequencies in red-figure. These results will be discussed in the context of these frequencies below.

### 4.3.3 Power law distributions.

As with the other samples, we will now compare the above results with an examination of the distribution of motifs found on oinochoe. The r square plots for all testable samples are shown in figures 4.3.14, 4.3.15 and 4.3.16, and summarised in table 4.3.7 and figure 4.3.12.

| | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|
| BF | 0.897 | | 0.946 | 0.992 | 0.931 | | | | |
| RF | | | | | 0.974 | 0.937 | 0.971 | 0.929 | 0.944 |
| BF and RF | 0.897 | | 0.948 | 0.995 | 0.951 | 0.937 | 0.971 | 0.849 | 0.944 |

Table 4.3.7. R-squared values.

| OINOCHOE | SAMPLE | N | mu | 1% | 5% | 10% |
|---|---|---|---|---|---|---|
| BF | 600 - 550 | 62 | 0.11 | ACCEPT | **REJECT** | **REJECT** |
| BF | 550 - 500 | 600 | 0.09 | ACCEPT | ACCEPT | **REJECT** |
| BF | 525 - 475 | 1010 | 0.04 | ACCEPT | ACCEPT | ACCEPT |
| BF | 500 - 450 | 50 | 0.02 | ACCEPT | ACCEPT | ACCEPT |
| RF | 500 - 450 | 96 | 0.15 | ACCEPT | ACCEPT | ACCEPT |
| RF | 475 - 425 | 202 | 0.10 | ACCEPT | ACCEPT | **REJECT** |
| RF | 450 - 400 | 528 | 0.05 | ACCEPT | ACCEPT | ACCEPT |
| RF | 425 - 375 | 248 | 0.03 | ACCEPT | ACCEPT | ACCEPT |
| RF | 400 - 300 | 349 | 0.02 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 600 - 550 | 62 | 0.11 | ACCEPT | **REJECT** | **REJECT** |
| BF AND RF | 550 - 500 | 605 | 0.10 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 525 - 475 | 1026 | 0.04 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 500 - 450 | 146 | 0.10 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 475 - 425 | 205 | 0.10 | ACCEPT | ACCEPT | **REJECT** |
| BF AND RF | 450 - 400 | 530 | 0.05 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 425 - 375 | 273 | 0.03 | ACCEPT | **REJECT** | **REJECT** |
| BF AND RF | 400 - 300 | 350 | 0.02 | ACCEPT | ACCEPT | ACCEPT |

Table 4.3.8. R-squared values, model and data comparison

The black-figure 600 - 550 date category and the joint black-figure and red-figure 425 - 375 date category are the only samples which reject the neutral model using the r-squared test. Otherwise, the r-squared values are very high, ranging from 92.59% to 99.5%. The red-figure 425 - 375 date category does not reject the neutral model, but the corresponding joint sample does. This is due to the presence of a very small number of additional black-figure pots which carry the same motifs as the red-figure pots already present. These additional motifs change the frequencies of the existing red-figure motifs and the resulting distribution, so that the sample goes from a fit of 92.9% in red-figure to a fit of 84.9% in black-figure and red-figure. As we will see throughout the shape sample results, the presence or absence of just a few motifs at key frequencies can change the test results.

| OINOCHOE RESULTS | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| sample | test | 600-550 | 575-525 | 550-500 | 525-475 | 500-450 | 475-425 | 450-400 | 425-375 | 400-300 |
| BF | R-squared | **X** | | **0** | **0** | **0** | | | | |
| | Theta | **0** | | **0** | **<** | **<** | | | | |
| RF | R-squared | | | | | **0** | **0** | **0** | **0** | **0** |
| | Theta | | | | | **0** | **0** | **>** | **>** | **0** |
| BF and RF | R-squared | **X** | | **0** | **0** | **0** | **0** | **0** | **X** | **0** |
| | Theta | **0** | | **0** | **<** | **0** | **0** | **>** | **>** | **0** |

**0** = neutral model not rejected **X** = neutral model rejected by 5% r-squared test

**>** = more diverse at 5% theta test **<** = less diverse at 5% theta test

Table 4.3.9. Summary of results.

## 4.4 Krater

### 4.4.1 Description

The Greeks used specific pots known as kraters to mix their wine with water. The jugs discussed in the previous sample were then used to transfer the resulting mixture into cups, though of course both could be used for water alone as well. Generally kraters were large free standing pots and were sometimes kept in a room adjacent to the symposium itself. After the “serious drinking on the dining couches” (Boardman 2001: 251), the krater would become the focus for song and dance.

| sample | shapes | N |
|---|---|---|
| Krater | | |
| | Krater | 3150 |
| | Dinos | 34 |
| | Psykter | 49 |

Table 4.4.1. Sample size

Kraters were made in a variety of forms, and can be divided into groups based on the shape and arrangement of the handles. All of these are considered together in this sample, as the context and decorative space available are very similar for each. These include the bell krater, calyx krater, column krater and volute krater, in addition to those which are identified simply as kraters. Also included in this sample is the dinos shape, which is not strictly a krater but which fulfilled the same function. Psykters are also included. Though very rare, their function and the social context in which they would be used is most similar to that of kraters.

| | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|---|
| BF | 4 | 32 | 74 | 158 | 116 | 3 | 0 | 0 | 0 | 0 |
| RF | 0 | 0 | 0 | 10 | 56 | 785 | 784 | 340 | 129 | 741 |
| BF and RF | 4 | 32 | 74 | 168 | 172 | 788 | 784 | 340 | 129 | 741 |

Table 4.4.2. Sample size over time.

The krater sample can be broken down by date as shown above in table 4.4.2 and figure 4.4.1. As can be seen, the krater shapes were very popular in the fifth century. Numbers decline sharply before a resurgence in the fourth century. The few that were produced early in black-figure were completely replaced by red-figure, with none of the lingering continuity seen in some other shapes.

| | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|---|
| BF new | 1 | 17 | 21 | 33 | 4 | 0 | 0 | 0 | 0 | 0 |
| BF total | 1 | 18 | 28 | 53 | 32 | 2 | 0 | 0 | 0 | 0 |
| RF new | 0 | 0 | 0 | 7 | 9 | 75 | 67 | 24 | 6 | 12 |
| RF total | 0 | 0 | 0 | 11 | 30 | 133 | 155 | 90 | 62 | 71 |
| BF and RF new | 1 | 17 | 21 | 37 | 13 | 75 | 67 | 24 | 6 | 12 |
| BF and RF total | 1 | 18 | 28 | 57 | 48 | 133 | 155 | 90 | 62 | 71 |

Table 4.4.3. New and total motifs.

Table 4.4.3 above shows the absolute number of motifs used, as well as the number of new motifs introduced in each period (see also figures 4.4.2 and 4.4.3). Both the number of new motifs introduced and the number of motifs in use overall track the pattern of the sample size, above, with the exception of the final date category, which does not show the same level of diversity or innovation of the previous periods despite containing roughly the same number of pots. The sharp rise in sample size in the 550 - 500 date category was matched by the introduction of a substantial number of new motifs, but this does not happen again at the end. This shows us that the number of motifs present in each sample is not determined simply by sample size.

| | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|
| BF mu | 0.53 | 0.28 | 0.21 | 0.03 | | | | | |
| BF drift | 0.00 | 0.15 | 0.05 | 0.22 | | | | | |
| RF mu | | | | 0.16 | 0.10 | 0.09 | 0.07 | 0.05 | 0.02 |
| RF drift | | | | -0.18 | -0.04 | 0.06 | 0.26 | 0.26 | 0.00 |
| BF and RF mu | 0.53 | 0.28 | 0.22 | 0.08 | 0.10 | 0.09 | 0.07 | 0.05 | 0.02 |
| BF and RF drift | 0.00 | 0.15 | 0.05 | 0.13 | -0.01 | 0.06 | 0.26 | 0.26 | 0.00 |

Table 4.4.4. Mutation and drift by technique and time period.

The mutation fraction for the krater sample is shown above in table 4.4.4. The early red-figure pots show a high level of innovation, but as in other samples, this is more a continuation of the  motifs used on earlier black-figure pots rather than a new burst of creativity. Once the red-figure technique is established, innovation steadily declines (figure 4.4.4).

Rates of drift and innovation are compared in figures 4.4.5, 4.4.6 and 4.4.7. As can be seen clearly in figure 4.4.5, innovation in black-figure starts very high and declines to almost nothing. It appears that a number of motifs were established early on, with very few motifs being added subsequently. Drift is low when the number of pots in the sample is high, in the 550 – 500 date category, but rises when that number declines in the 525 - 475 date category, as it does at the end of most black-figure shape samples. In red-figure (figure 4.4.6), motifs are added to each sample in increasing numbers, until drift and innovation almost meet in the 475 - 425 date category. As the number of pots in the sample declines again, in the 450 - 400 and 425 - 375 date categories, drift becomes very high, until returning to near equilibrium in the 400 - 300 date category.

### 4.4.2 Estimates of theta

The results of our estimates of theta for our krater sample are shown below in table 4.4.5 and in figures 4.4.8, 4.4.9 and 4.4.10. As can be seen, diversity levels measured by actual frequency (tF) of variants are consistently lower than those expected by tE. This leads us to expect that the krater sample will show signs of conformist bias, with fewer motifs appearing at medium to high frequencies than would be expected under neutral conditions.

| | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|---|
| BF tE | | 17.811 | 16.864 | 28.387 | 14.946 | | | | | |
| BF tF | | 29.118 | 8.938 | 4.194 | 5.111 | | | | | |
| RF tE | | | | | 27.029 | 46.179 | 58.169 | 40.290 | 47.527 | 19.516 |
| RF tF | | | | | 10.042 | 23.131 | 19.834 | 12.105 | 3.574 | 3.202 |
| BF and RF tE | | 17.811 | 16.864 | 30.785 | 22.428 | 46.093 | 58.169 | 40.290 | 47.527 | 19.516 |
| BF and RF tF | | 29.118 | 8.938 | 4.627 | 6.789 | 23.080 | 19.834 | 12.105 | 3.574 | 3.202 |

Table 4.4.5. Estimates of theta.

| KRATER | SAMPLE | N | mu | 1% | 5% | 10% | tf-te at 5% level |
|---|---|---|---|---|---|---|---|
| BF | 575 - 525 | 74 | 0.28 | ACCEPT | ACCEPT | ACCEPT | |
| BF | 550 - 500 | 158 | 0.21 | ACCEPT | ACCEPT | ACCEPT | |
| BF | 525 - 475 | 116 | 0.03 | **REJECT** | **REJECT** | **REJECT** | less diverse |
| RF | 525 - 475 | 56 | 0.16 | ACCEPT | ACCEPT | ACCEPT | |
| RF | 500 - 450 | 785 | 0.10 | ACCEPT | ACCEPT | ACCEPT | |
| RF | 475 - 425 | 784 | 0.09 | ACCEPT | ACCEPT | ACCEPT | |
| RF | 450 - 400 | 340 | 0.07 | **REJECT** | **REJECT** | **REJECT** | less diverse |
| RF | 425 - 375 | 129 | 0.05 | **REJECT** | **REJECT** | **REJECT** | less diverse |
| RF | 400 - 300 | 741 | 0.02 | **REJECT** | **REJECT** | **REJECT** | less diverse |
| BF AND RF | 575 - 525 | 74 | 0.28 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 550 - 500 | 168 | 0.22 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 525 - 475 | 172 | 0.08 | ACCEPT | ACCEPT | **REJECT** | |
| BF AND RF | 500 - 450 | 788 | 0.10 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 475 - 425 | 784 | 0.09 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 450 - 400 | 340 | 0.07 | **REJECT** | **REJECT** | **REJECT** | less diverse |
| BF AND RF | 425 - 375 | 129 | 0.05 | **REJECT** | **REJECT** | **REJECT** | less diverse |
| BF AND RF | 400 - 300 | 741 | 0.02 | **REJECT** | **REJECT** | **REJECT** | less diverse |

Table 4.4.6. Comparison of |tf-te| for model and data.

When we compare the data with the model (table 4.4.6 above) we find this is indeed the case for the latter half of our sample at the 5% level of significance. During the early and middle periods of krater production, however, the diversity of motifs used does not deviate from the expectations of the neutral model. It is only at the end, from 450 BC onwards, that diversity contracts. This is not due to sample size alone, as the final phase of production, date category 400 - 300, contains 741 pots yet still fails to reach the level of diversity predicted by the neutral model for that sample size and level of innovation.

### 4.4.3 Power laws

The r square values for all samples containing more than 50 pots are shown below in table 4.4.7 and figure 4.4.12. The plots themselves are shown in figures 4.4.14, 4.4.15 and 4.4.16, with a summary of the r-squared values shown in figure 4.4.12.

| | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|
| BF | | 0.976 | 0.936 | 0.978 | | | | | |
| RF | | | | 0.768 | 0.984 | 0.980 | 0.963 | 0.978 | 0.986 |
| BF and RF | | 0.976 | 0.935 | 0.965 | 0.984 | 0.980 | 0.963 | 0.978 | 0.986 |

Table 4.4.7. R-squared values.

| KRATER | SAMPLE | N | mu | 1% | 5% | 10% |
|---|---|---|---|---|---|---|
| BF | 575 - 525 | 74 | 0.28 | ACCEPT | ACCEPT | ACCEPT |
| BF | 550 - 500 | 158 | 0.21 | **REJECT** | **REJECT** | **REJECT** |
| BF | 525 - 475 | 116 | 0.03 | ACCEPT | ACCEPT | ACCEPT |
| RF | 525 - 475 | 56 | 0.16 | **REJECT** | **REJECT** | **REJECT** |
| RF | 500 - 450 | 785 | 0.10 | ACCEPT | ACCEPT | ACCEPT |
| RF | 475 - 425 | 784 | 0.09 | ACCEPT | ACCEPT | ACCEPT |
| RF | 450 - 400 | 340 | 0.07 | ACCEPT | ACCEPT | ACCEPT |
| RF | 425 - 375 | 129 | 0.05 | ACCEPT | ACCEPT | ACCEPT |
| RF | 400 - 300 | 741 | 0.02 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 575 - 525 | 74 | 0.28 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 550 - 500 | 168 | 0.22 | **REJECT** | **REJECT** | **REJECT** |
| BF AND RF | 525 - 475 | 172 | 0.08 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 500 - 450 | 788 | 0.10 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 475 - 425 | 784 | 0.09 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 450 - 400 | 340 | 0.07 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 425 - 375 | 129 | 0.05 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 400 - 300 | 741 | 0.02 | ACCEPT | ACCEPT | ACCEPT |

Table 4.4.8. R-squared values, model and data comparison

As in previous samples, the r-squared values are once again very high, indicating that the motifs in the krater sample are arranged according to a power law, with a few very high frequency motifs and many low frequency motifs and a linear distribution between. The notable exception is the first date category in the red-figure, 525 - 475, which shows only a 76.8% r-squared fit. When we compare these results to the results of the model in table 4.4.8, we see that this value is lower than that produced by our model, and this test therefore rejects the neutral model. When combined with the corresponding black-figure sample, the 525 - 475 date category does not reject the neutral model. The only other sample to reject the neutral model is the black-figure 550 – 500 date category and the corresponding joint sample.

| KRATER RESULTS | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| sample | test | 600-550 | 575-525 | 550-500 | 525-475 | 500-450 | 475-425 | 450-400 | 425-375 | 400-300 |
| BF | R-squared | | **0** | **X** | **0** | | | | | |
| | Theta | | **0** | **0** | **<** | | | | | |
| RF | R-squared | | | | **X** | **0** | **0** | **0** | **0** | **0** |
| | Theta | | | | **0** | **0** | **0** | **<** | **<** | **<** |
| BF and RF | R-squared | | **0** | **X** | **0** | **0** | **0** | **0** | **0** | **0** |
| | Theta | | **0** | **0** | **0** | **0** | **0** | **<** | **<** | **<** |

**0** = neutral model not rejected **X** = neutral model rejected by 5% r-squared test

**>** = more diverse at 5% theta test **<** = less diverse at 5% theta test

Table 4.4.9. Summary of results.

## 4.5 Lekythoi

### 4.5.1 Description

Olive oil was a valuable commodity in the Greek economy. It was transported in undecorated amphorae or leather skins, but when it came to be sold and used it was decanted into specially designed oil flasks. These could range in size from tiny vases for perfumed oil to large cylindrical lekythoi which were placed in graves as an offering to the dead. It is because of this practice that so many of this type have survived. Anywhere Greek cemeteries are found, vast quantities of lekythoi are exhumed, and they therefore compose more than a quarter of the total number of pots in our sample.

| sample | shapes | N |
|---|---|---|
| Lekythoi | | |
| | Lekythos | 11642 |
| | Aryballos | 36 |
| | Alabastron | 424 |
| | Askos | 224 |
| | Plemochoe | 3 |
| | Lydion | 6 |

Table 4.5.1. Sample size

Our sample of lekythoi can be broken down as seen above. The lekythos shape includes its derivative, the squat lekythos, which was simply a shorter and broader version of the vase which served the same function. The other shapes, produced in comparatively tiny quantities, also were designed to hold oil and had a similar form, hypothesised to derive from the pendulous shape of a heavy full oil skin (Boardman 2001: 258).

| technique | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|---|
| BF | 9 | 46 | 107 | 982 | 4159 | 1161 | 89 | 7 | 1 | 1 |
| RF | 0 | 0 | 0 | 9 | 106 | 910 | 2500 | 1483 | 431 | 334 |
| BF and RF | 9 | 46 | 107 | 991 | 4265 | 2071 | 2589 | 1490 | 432 | 335 |

Table 4.5.2. Sample size over time.

The lekythoi sample can be broken down by technique and year as shown above in table 4.5.2 and figure 4.5.1. Black-figure lekythoi were produced in vast quantities in the 525 - 475 date category, followed by near total replacement by red-figure lekythoi by the 475 - 425 date category. Red-figure lekythoi peak in popularity during the 475 - 425 date category and then steadily decline until the end of the study period. The resurgent rise in popularity during the 400 - 300 date category that we saw in the symposium shapes discussed thus far does not occur in lekythoi.

The above samples also include several hundred white ground lekythoi, both black-figure/ white ground and red-figure/white ground. These are grouped with their main technique samples, as either red-figure or black-figure, as their numbers are too few to analyse on their own. Trends in sub-techniques are discussed in detail in chapter 6.

Table 4.5.3 below and figures 4.5.2 shows the number of motifs in use on lekythoi, both as a total and as the number of new motifs introduced. By comparing these figures with table 4.5.2 above, we see that the peak of black-figure lekythoi production was matched by a peak in the total number of motifs in use, during the 525 - 475 date category. However, the total number of new motifs introduced (figure 4.5.3) was 71, only one more than the previous date category, despite there being more than four times the number of pots in the sample. Once again, we see that sample size alone does not determine the dynamics of the motif frequencies.

The red-figure lekythoi show remarkable continuity in the number of motifs in use, especially between the date categories of 475 - 425 and 450 - 400 (figure 4.5.2). During this time, however, the number of new motifs rises from 27 to 42, while the total number of motifs dropped by 1. This shows that as the popularity of lekythoi started to decline, many more motifs were introduced. Our theta tests should therefore show signs of novelty bias for these date categories.

| | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|---|
| BF new | 5 | 11 | 20 | 71 | 72 | 16 | 0 | 0 | 0 | 0 |
| BF total | 5 | 13 | 28 | 100 | 164 | 94 | 9 | 0 | 0 | 0 |
| RF new | 0 | 0 | 0 | 1 | 1 | 14 | 26 | 42 | 1 | 4 |
| RF total | 0 | 0 | 0 | 5 | 20 | 73 | 102 | 103 | 31 | 40 |
| BF and RF new | 5 | 11 | 20 | 72 | 72 | 29 | 26 | 42 | 1 | 4 |
| BF and RF total | 5 | 13 | 28 | 101 | 164 | 127 | 103 | 103 | 31 | 40 |

Table 4.5.3. New and total motifs.

| | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|
| BF mu | 0.24 | 0.19 | 0.07 | 0.02 | 0.01 | 0.00 | | | |
| BF drift | 0.07 | 0.05 | 0.00 | 0.00 | 0.07 | 0.96 | | | |
| RF mu | | | | 0.01 | 0.02 | 0.01 | 0.03 | 0.00 | 0.01 |
| RF drift | | | | -0.13 | -0.04 | 0.00 | 0.03 | 0.17 | -0.01 |
| BF and RF mu | 0.24 | 0.19 | 0.07 | 0.02 | 0.01 | 0.01 | 0.03 | 0.00 | 0.01 |
| BF and RF drift | 0.07 | 0.05 | 0.00 | 0.00 | 0.03 | 0.02 | 0.03 | 0.17 | -0.01 |

Table 4.5.4. Mutation and drift by technique and time period.

The mutation fractions of the lekythoi sample are shown above in table 4.5.4 and in figure 4.5.4. As is characteristic of the relatively small early black-figure samples, the mutation fraction is high, due to each date category containing a very large number of new motifs divided amongst very few pots. After this, innovation is extremely low throughout. When the red-figure technique is introduced during the 525 - 475 date category, there is no corresponding rise in innovation, even in the first few samples, which normally show exaggerated levels of innovation similar to those found in early black-figure. This shows that all of the motifs used on red-figure lekythoi were carried over from earlier black-figure models.

Comparisons of rates of drift and innovation are shown in figures 4.5.5, 4.5.6 and 4.5.7. In figure 4.5.5 we see that drift and mutation are closely matched in black-figure, with the exception of the final date category, 500 - 450, in which black-figure lekythoi production grinds to a halt. In red-figure (figure 4.5.6), we see that the mutation rate is nearly flat, and that the rate of drift in early periods is negative (this is the effect of motifs being copied from black-figure). After this, we see substantial deviation from equilibrium in the 425 - 375 date category, caused by the huge drop in sample size from 1483 in the 450 - 400 date category to 431 in the 425 - 375 date category. After this, though the sample size decreases again to 334, drift and mutation return to near equilibrium. Figure 5.07 shows that after the initial phases of very high mutation, the combined sample is at near equilibrium throughout, with the exception of the 425 - 375 date category. We expect the neutral model to be rejected during this period.

### 4.5.2 Estimates of theta

The results of our estimates of theta for lekythoi are shown below in table 4.5.5 and in figures 4.5.8, 4.5.9 and 4.5.10. As can be seen, the tF value for the black-figure 475 - 425 date category is an order of magnitude larger than seen in any other sample. This date category corresponds with a huge drop in sample size, as discussed above. During this period there were 9 motifs found on the 89 lekythoi, which means that there was one motif for every ten lekythoi. Following the calculations for tF, this gives us a value of theta of 329. Naturally, we expect this date category to reject the neutral model.

| | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|---|
| BF tE | | 6.375 | 12.663 | 28.034 | 34.207 | 24.309 | 2.675 | | | |
| BF tF | | 10.756 | 23.835 | 9.529 | 9.160 | 45.525 | 329.042 | | | |
| RF tE | | | | | 7.544 | 18.857 | 21.514 | 25.320 | 7.816 | 12.057 |
| RF tF | | | | | 31.950 | 50.168 | 39.771 | 141.404 | 38.983 | 52.607 |
| BF and RF tE | | 6.375 | 14.191 | 28.705 | 33.985 | 30.621 | 22.639 | 25.928 | 8.474 | 12.889 |
| BF and RF tF | | 10.756 | 23.835 | 9.598 | 9.442 | 71.199 | 42.513 | 142.752 | 39.169 | 52.928 |

Table 4.5.5. Estimates of theta.

| LEKYTHOI | SAMPLE | N | mu | 1% | 5% | 10% | tf-te at 5% level |
|---|---|---|---|---|---|---|---|
| BF | 575 - 525 | 107 | 0.19 | ACCEPT | ACCEPT | ACCEPT | |
| BF | 550 - 500 | 982 | 0.07 | ACCEPT | ACCEPT | ACCEPT | |
| BF | 525 - 475 | 4159 | 0.02 | ACCEPT | ACCEPT | **REJECT** | |
| BF | 500 - 450 | 1161 | 0.01 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| BF | 475 - 425 | 89 | 0.00 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| RF | 525 - 475 | 106 | 0.01 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| RF | 500 - 450 | 910 | 0.02 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| RF | 475 - 425 | 2500 | 0.01 | ACCEPT | **REJECT** | **REJECT** | more diverse |
| RF | 450 - 400 | 1483 | 0.03 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| RF | 425 - 375 | 431 | 0.00 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| RF | 400 - 300 | 334 | 0.01 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| BF AND RF | 575 - 525 | 107 | 0.19 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 550 - 500 | 991 | 0.07 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 525 - 475 | 4265 | 0.02 | ACCEPT | ACCEPT | **REJECT** | |
| BF AND RF | 500 - 450 | 2071 | 0.01 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| BF AND RF | 475 - 425 | 2589 | 0.01 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| BF AND RF | 450 - 400 | 1490 | 0.03 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| BF AND RF | 425 - 375 | 432 | 0.00 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| BF AND RF | 400 - 300 | 335 | 0.01 | **REJECT** | **REJECT** | **REJECT** | more diverse |

Table 4.5.6. Comparison of |tf-te| for model and data.

Indeed, this is the case. When we compare our data with the model (table 4.5.6 above), we see that only the early black-figure lekythoi conform to the neutral model and that every date category of red-figure lekythoi is more diverse than predicted.

### 4.5.3 Power laws

We can now compare these results with power law regressions for each date category of our sample as well as each technique sample overall. Figures 5.14, 5.15 and 5.16 and the results in table 4.5.7 show very good r-squared values for all power law regressions for each sample. Of course we cannot evaluate these results until we compare them with the results for corresponding N and mu values in the model.

| | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|
| BF | | 0.950 | 0.993 | 0.984 | 0.977 | 1.0 | | | |
| RF | | | | 0.946 | 0.973 | 0.979 | 0.966 | 0.834 | 0.980 |
| BF and RF | | 0.950 | 0.992 | 0.981 | 0.991 | 0.979 | 0.966 | 0.834 | 0.980 |

Table 4.5.7. R-squared values.

| LEKYTHOI | SAMPLE | N | mu | 1% | 5% | 10% |
|---|---|---|---|---|---|---|
| BF | 575 - 525 | 107 | 0.19 | ACCEPT | ACCEPT | **REJECT** |
| BF | 550 - 500 | 982 | 0.07 | ACCEPT | ACCEPT | ACCEPT |
| BF | 525 - 475 | 4159 | 0.02 | ACCEPT | ACCEPT | ACCEPT |
| BF | 500 - 450 | 1161 | 0.01 | ACCEPT | ACCEPT | ACCEPT |
| BF | 475 - 425 | 89 | 0.00 | ACCEPT | ACCEPT | ACCEPT |
| RF | 525 - 475 | 106 | 0.01 | ACCEPT | ACCEPT | ACCEPT |
| RF | 500 - 450 | 910 | 0.02 | ACCEPT | ACCEPT | ACCEPT |
| RF | 475 - 425 | 2500 | 0.01 | ACCEPT | ACCEPT | ACCEPT |
| RF | 450 - 400 | 1483 | 0.03 | ACCEPT | ACCEPT | ACCEPT |
| RF | 425 - 375 | 431 | 0.00 | ACCEPT | **REJECT** | **REJECT** |
| RF | 400 - 300 | 334 | 0.01 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 575 - 525 | 107 | 0.21 | ACCEPT | ACCEPT | **REJECT** |
| BF AND RF | 550 - 500 | 991 | 0.07 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 525 - 475 | 4265 | 0.02 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 500 - 450 | 2071 | 0.01 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 475 - 425 | 2589 | 0.01 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 450 - 400 | 1490 | 0.03 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 425 - 375 | 432 | 0.00 | ACCEPT | **REJECT** | **REJECT** |
| BF AND RF | 400 - 300 | 335 | 0.01 | ACCEPT | ACCEPT | ACCEPT |

Table 4.5.8. R-squared values, model and data comparison

The model comparison results are shown in table 4.5.8 above. As can be seen, only one sample, the red-figure 425 - 375 date category and the corresponding joint sample, rejects the neutral model using the r-squared test at the 5% level. At the 10% level of significance, we can reject only two individual samples and their corresponding combined BF and RF samples.

| LEKYTHOI RESULTS | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| sample | test | 600-550 | 575-525 | 550-500 | 525-475 | 500-450 | 475-425 | 450-400 | 425-375 | 400-300 |
| BF | R-squared | | **0** | **0** | **0** | **0** | **0** | | | |
| | Theta | | **0** | **0** | **0** | **>** | **>** | | | |
| RF | R-squared | | | | **0** | **0** | **0** | **0** | **X** | **0** |
| | Theta | | | | **>** | **>** | **>** | **>** | **>** | **>** |
| BF and RF | R-squared | | **0** | **0** | **0** | **0** | **0** | **0** | **X** | **0** |
| | Theta | | **0** | **0** | **0** | **>** | **>** | **>** | **>** | **>** |

**0** = neutral model not rejected **X** = neutral model rejected by 5% r-squared test

**>** = more diverse at 5% theta test **<** = less diverse at 5% theta test

Table 4.5.9. Summary of results.

## 4.6 Amphorae

### 4.6.1 Description

An amphorae is a large vessel for storing or transporting granular solids and liquids such as wine and oil. The vast majority that were produced were undecorated coarse-ware, but a large number of fine figure-painted examples have survived.

| sample | shapes | N |
|---|---|---|
| Amphorae | | |
| | Amphora | 5409 |
| | Pelike | 1549 |
| | Stamnos | 400 |

Table 4.6.1. Sample size

The sample of amphorae includes the shapes above. Also included in this sample are all the different sub-types of amphora, including neck amphora and bail amphora. These are not sufficiently different from one another to warrant independent examination. The pelike is a kind of low rounded amphora, and is virtually indistinguishable from a belly amphora. The stamnos is shorter and more rounded and was used for the same liquid storage purposes as the amphora itself.

| | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 -375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|---|
| BF | 21 | 161 | 729 | 2255 | 923 | 96 | 5 | 4 | 4 | 56 |
| RF | 0 | 0 | 0 | 36 | 138 | 942 | 1053 | 461 | 76 | 398 |
| BF and RF | 21 | 161 | 729 | 2291 | 1061 | 1038 | 1058 | 465 | 80 | 454 |

Table 4.6.2. Sample size over time.

Amphorae occur in very large numbers throughout the three centuries of this study, as shown in table 4.6.2 and figure 4.6.1. The largest sample occurs in black-figure in the 550 - 500 date category. This is followed by lower but steady sample sizes until the 425 - 375 date category, when production dropped off sharply, with a brief resumption in the 400 - 300 date category. As with many of the shape samples, the combined black-figure and red-figure sample sizes are stable across the black-figure/ red-figure divide in the 525 - 475 date category.

Though it is widely acknowledged that production of black-figure amphorae went on through the red-figure period due to their use as prizes in games (the Panathenaic amphora), the number of black-figure pots in the later years of our sample is quite small. Panathenaic amphorae are included in this sample due to the likelihood that not all prize amphorae are identified as such in the original Beazley source material. Regardless, the shape and size of the Panathenaic amphora is so similar to that of the regular amphora that there is no need at this stage to consider it separately.

The distribution of new motifs and the total number of motifs for each date category in the amphorae sample are shown below in table 4.6.3 and in figure 4.6.2. The data show that when the samples are largest, in the 550 - 500 date category, the number of motifs in use is not substantially greater than in the preceding and following date category, when both red-figure and black-figure are viewed together. The number of new motifs introduced, however, peaks very early in the black-figure sample and then declines sharply, followed by another lower peak in red-figure in the 500 - 450 date category, which subsequently stabilises and then drops off completely. As we have seen, this two-peak pattern is typical for many of the shapes in our sample.

| | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 -375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|---|
| BF new | 6 | 23 | 91 | 65 | 16 | 3 | 0 | 0 | 0 | 3 |
| BF total | 6 | 26 | 117 | 146 | 99 | 41 | 6 | 4 | 6 | 15 |
| RF new | 0 | 0 | 0 | 5 | 10 | 40 | 40 | 22 | 1 | 4 |
| RF total | 0 | 0 | 0 | 30 | 55 | 140 | 139 | 75 | 34 | 53 |
| BF and RF new | 6 | 23 | 91 | 68 | 26 | 43 | 40 | 22 | 1 | 7 |
| BF and RF total | 6 | 26 | 117 | 150 | 117 | 148 | 139 | 75 | 37 | 63 |

Table 4.6.3. New and total motifs.

| | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 -375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|
| BF mu | 0.14 | 0.12 | 0.03 | 0.02 | 0.03 | | | | 0.05 |
| BF drift | 0.02 | 0.00 | 0.02 | 0.07 | 0.64 | | | | -0.11 |
| RF mu | | | 0.14 | 0.07 | 0.04 | 0.04 | 0.05 | 0.01 | 0.01 |
| RF drift | | | -0.69 | -0.11 | -0.05 | 0.04 | 0.19 | 0.55 | -0.04 |
| BF and RF mu | 0.14 | 0.12 | 0.03 | 0.02 | 0.04 | 0.04 | 0.05 | 0.01 | 0.02 |
| BF and RF drift | 0.02 | 0.00 | 0.02 | 0.06 | 0.01 | 0.05 | 0.18 | 0.49 | -0.04 |

Table 4.6.4. Mutation and drift by technique and time period.

The mutation fraction for amphorae is shown above in table 4.6.4 and in figure 4.6.4. A number of new motifs were introduced along with the red-figure technique in the 525 - 475 date category, giving this period a 7% mutation rate, but as with other samples, when the number of variants introduced is considered as part of the combined BF and RF sample, the mutation fraction is actually quite low, at only 2%.

The mutation and drift rates are shown in figures 4.6.5, 4.6.6 and 4.6.7. In figure 4.6.5 we see that in black-figure amphorae, after the initially high rates of mutation caused by the first appearance of many staple motifs early in the sample, rates of drift and innovation are close together until the 500 – 450 date category, at which point the sample size collapses and nearly all motifs are not copied. In figure 4.6.6 we see that in red-figure the pattern of the relationship between drift and innovation is very similar to that seen in previous shape samples. Drift starts very low, as a reflection of the number of motifs copied from black-figure pots, then approaches equilibrium from the 525 - 400 date category. In the 425 - 375 date category we see that drift is very high, due to the large number of motifs not copied as an effect of the sharp decrease in sample size. In the 400 - 300 date category near equilibrium is restored. In the combined sample (figure 4.6.7) we see that from 550 BC onward drift and mutation occur at very similar rates with the exception of the 450 - 400 and 425 - 375 date categories, due to the sharp reduction in sample size after the 475 - 425 date category.

### 4.6.2 Estimates of theta

The results of theta measurements for the amphorae are shown in table 4.6.5 below and figures 4.6.8, 4.6.9 and 4.6.10. There is a gap in the measurable quantities of pots towards the end of the black-figure sample, caused by the very low sample sizes of black-figure amphorae in the intervening periods. In the BF and RF combined sample we have measurements of theta for every period, which is unique in the shapes examined. Naturally the first period is not considered in comparison with the model, as there is no way to measure mutation without at least one preceding step.

| | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 -375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|---|
| BF tE | 3.144 | 9.009 | 39.614 | 35.049 | 28.303 | 27.609 | | | | 7.040 |
| BF tF | 48.000 | 25.236 | 8.087 | 4.541 | 4.933 | 2.879 | | | | 0.609 |
| RF tE | | | | 87.363 | 34.342 | 45.712 | 43.103 | 25.641 | 24.188 | 16.626 |
| RF tF | | | | 3.645 | 16.408 | 35.175 | 33.979 | 49.940 | 39.965 | 10.112 |
| BF and RF tE | 3.144 | 9.009 | 39.614 | 36.129 | 33.772 | 47.429 | 43.017 | 25.537 | 27.306 | 20.075 |
| BF and RF tF | 48.000 | 25.236 | 8.087 | 4.578 | 5.790 | 30.378 | 34.048 | 49.650 | 36.427 | 11.336 |

Table 4.6.5. Estimates of theta.

| AMPHORAE | SAMPLE | N | mu | 1% | 5% | 10% | tf-te at 5% level |
|---|---|---|---|---|---|---|---|
| BF | 600 - 550 | 161 | 0.14 | ACCEPT | ACCEPT | ACCEPT | |
| BF | 575 - 525 | 729 | 0.12 | ACCEPT | ACCEPT | ACCEPT | |
| BF | 550 - 500 | 2255 | 0.03 | ACCEPT | **REJECT** | **REJECT** | less diverse |
| BF | 525 - 475 | 923 | 0.02 | **REJECT** | **REJECT** | **REJECT** | less diverse |
| BF | 500 - 450 | 96 | 0.03 | **REJECT** | **REJECT** | **REJECT** | less diverse |
| BF | 400 - 300 | 56 | 0.05 | ACCEPT | **REJECT** | **REJECT** | less diverse |
| RF | 525 - 475 | 138 | 0.07 | **REJECT** | **REJECT** | **REJECT** | less diverse |
| RF | 500 - 450 | 942 | 0.04 | ACCEPT | ACCEPT | ACCEPT | |
| RF | 475 - 425 | 1053 | 0.04 | ACCEPT | ACCEPT | ACCEPT | |
| RF | 450 - 400 | 461 | 0.05 | ACCEPT | **REJECT** | **REJECT** | more diverse |
| RF | 425 - 375 | 76 | 0.01 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| RF | 400 - 300 | 398 | 0.01 | ACCEPT | **REJECT** | **REJECT** | less diverse |
| BF AND RF | 600 - 550 | 161 | 0.14 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 575 - 525 | 729 | 0.12 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 550 - 500 | 2291 | 0.03 | ACCEPT | **REJECT** | **REJECT** | less diverse |
| BF AND RF | 525 - 475 | 1061 | 0.02 | **REJECT** | **REJECT** | **REJECT** | less diverse |
| BF AND RF | 500 - 450 | 1038 | 0.04 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 475 - 425 | 1058 | 0.04 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 450 - 400 | 465 | 0.05 | ACCEPT | **REJECT** | **REJECT** | more diverse |
| BF AND RF | 425 - 375 | 80 | 0.01 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| BF AND RF | 400 - 300 | 454 | 0.02 | ACCEPT | ACCEPT | **REJECT** | |

Table 4.6.6. Comparison of |tf-te| for model and data.

The results of our comparison with the model are shown above in table 4.6.6. As can be seen, the results are mixed, with early periods of black-figure and red-figure tending to not reject the neutral model and the later periods rejecting the neutral model. The black-figure sample begins with two date categories which do not reject the neutral model, followed by four date categories which all show less diversity than expected at the 5% level of significance. The red-figure sample begins less diverse, becomes neutral for two date categories (500 - 450 and 475 - 425), becomes more diverse than expected in the 450 - 400 and 425 - 375 date categories and is then less diverse again in the final 400 - 300 date category. Though both the red-figure and black-figure samples on their own are less diverse than expected in the 400 - 300 date category, when the two samples are combined, they no longer reject the neutral model at the 5% level (though they continue to at the 10% level), for reasons which will be examined below.

### 4.6.3 Power laws

We can now compare these results with the results of our power law analysis. The r-squared values for our amphorae samples are shown in table 4.6.7 below and in figures 4.6.12 to 4.6.16. The calculated r-squared values are very high for all samples, with the exception of the red-figure 550 - 500, red-figure 425 - 375 and the combined black-figure and red-figure 425 - 375 date categories. The red-figure 550 - 500 date category is made up of only 36 pots and is therefore not used in our model comparison.

| | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 -375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|
| BF | 0.913 | 0.972 | 0.989 | 0.991 | 0.980 | | | | 0.864 |
| RF | | | | 0.936 | 0.975 | 0.978 | 0.930 | 0.839 | 0.959 |
| BF and RF | 0.913 | 0.972 | 0.989 | 0.978 | 0.991 | 0.974 | 0.936 | 0.720 | 0.940 |

Table 4.6.7. R-squared values.

| AMPHORAE | SAMPLE | N | mu | 1% | 5% | 10% |
|---|---|---|---|---|---|---|
| BF | 600 - 550 | 161 | 0.14 | **REJECT** | **REJECT** | **REJECT** |
| BF | 575 - 525 | 729 | 0.12 | ACCEPT | ACCEPT | ACCEPT |
| BF | 550 - 500 | 2255 | 0.03 | ACCEPT | ACCEPT | ACCEPT |
| BF | 525 - 475 | 923 | 0.02 | ACCEPT | ACCEPT | ACCEPT |
| BF | 500 - 450 | 96 | 0.03 | ACCEPT | ACCEPT | ACCEPT |
| BF | 400 - 300 | 56 | 0.05 | ACCEPT | ACCEPT | ACCEPT |
| RF | 525 - 475 | 138 | 0.07 | ACCEPT | ACCEPT | ACCEPT |
| RF | 500 - 450 | 942 | 0.04 | ACCEPT | ACCEPT | ACCEPT |
| RF | 475 - 425 | 1053 | 0.04 | ACCEPT | ACCEPT | ACCEPT |
| RF | 450 - 400 | 461 | 0.05 | ACCEPT | ACCEPT | **REJECT** |
| RF | 425 - 375 | 76 | 0.01 | ACCEPT | ACCEPT | ACCEPT |
| RF | 400 - 300 | 398 | 0.01 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 600 - 550 | 161 | 0.14 | **REJECT** | **REJECT** | **REJECT** |
| BF AND RF | 575 - 525 | 729 | 0.12 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 550 - 500 | 2291 | 0.03 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 525 - 475 | 1061 | 0.02 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 500 - 450 | 1038 | 0.04 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 475 - 425 | 1058 | 0.04 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 450 - 400 | 465 | 0.05 | ACCEPT | ACCEPT | **REJECT** |
| BF AND RF | 425 - 375 | 80 | 0.01 | ACCEPT | ACCEPT | **REJECT** |
| BF AND RF | 400 - 300 | 454 | 0.02 | ACCEPT | ACCEPT | ACCEPT |

Table 4.6.8. R-squared values, model and data comparison

The results of our model comparison are shown above. At the 5% level of significance, only the first black-figure date category and the corresponding BF and RF sample reject the neutral model. All other samples have r-squared values within the range predicted by our model, even the red-figure 425 - 375 date category which appeared to be very low. These results illustrate that r-squared values on their own are impossible to interpret without an external frame of reference, which our model provides.

| AMPHORAE RESULTS | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| sample | test | 600-550 | 575-525 | 550-500 | 525-475 | 500-450 | 475-425 | 450-400 | 425-375 | 400-300 |
| BF | R-squared | **X** | **0** | **0** | **0** | **0** | | | | **0** |
| | Theta | **0** | **0** | **<** | **<** | **<** | | | | **<** |
| RF | R-squared | | | | **0** | **0** | **0** | **0** | **0** | **0** |
| | Theta | | | | **<** | **0** | **0** | **>** | **>** | **<** |
| BF and RF | R-squared | **X** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** |
| | Theta | **0** | **0** | **<** | **<** | **0** | **0** | **>** | **>** | **0** |

**0** = neutral model not rejected **X** = neutral model rejected by 5% r-squared test

**>** = more diverse at 5% theta test **<** = less diverse at 5% theta test

Table 4.6.9. Summary of results.

## 4.7 Hydria

### 4.7.1 Description

Hydria were used for transporting and decanting water. This type of vase was large and had two lug handles for lifting as well as a third handle for pouring. Figure decoration was arranged around the sides in large panels.

| sample | shapes | N |
|---|---|---|
| Hydria | | |
| | Hydria | 1740 |

Table 4.7.1. Sample size

Our sample is composed entirely of hydria, with no sub-types and no related shapes.

| technique | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 -375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|---|
| BF | 1 | 21 | 117 | 439 | 187 | 10 | 0 | 0 | 0 | 0 |
| RF | 0 | 0 | 0 | 7 | 59 | 206 | 285 | 207 | 64 | 137 |
| BF and RF | 1 | 21 | 117 | 446 | 246 | 216 | 285 | 207 | 64 | 137 |

Table 4.7.2. Sample size over time.

The distribution of hydria in our sample by date is shown in table 4.7.2 above and in figure 4.7.1. The largest single sample appears in the black-figure 550 - 500 date category. This is followed by relatively stable sample sizes with a much lower peak in the red-figure 475 - 425 date category. As we have seen in many other shapes, sample size collapses in the 425 - 375 date category, followed by a small rise in the 400 - 300 date category. Once red-figure hydria are established in the 500 - 450 date category, they completely replace black-figure.

| | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 -375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|---|
| BF new | 1 | 7 | 39 | 54 | 6 | 0 | 0 | 0 | 0 | 0 |
| BF total | 1 | 8 | 45 | 93 | 51 | 9 | 0 | 0 | 0 | 0 |
| RF new | 0 | 0 | 0 | 4 | 7 | 37 | 40 | 28 | 3 | 12 |
| RF total | 0 | 0 | 0 | 7 | 39 | 95 | 97 | 71 | 36 | 58 |
| BF and RF new | 1 | 7 | 39 | 55 | 13 | 37 | 40 | 28 | 3 | 12 |
| BF and RF total | 1 | 8 | 45 | 94 | 66 | 97 | 97 | 71 | 36 | 58 |

Table 4.7.3. New and total motifs.

We can see from the absolute numbers of motifs shown in table 4.7.3 above and figure 4.7.2 that the number of motifs introduced follows the pattern set by the other shape samples, with more motifs being introduced during periods with more hydria and fewer in periods with few hydria (figure 4.7.3). The number of motifs in use, however, is fairly stable, and is actually slightly higher during the red-figure period than during the peak of the black-figure period, despite there being fewer red-figure pots in the samples.

| | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 -375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|
| BF mu | | 0.33 | 0.12 | 0.03 | | | | | |
| BF drift | | 0.02 | 0.01 | 0.26 | | | | | |
| RF mu | | | | 0.12 | 0.18 | 0.14 | 0.14 | 0.05 | 0.09 |
| RF drift | | | | -0.42 | -0.09 | 0.13 | 0.26 | 0.59 | -0.07 |
| BF and RF mu | | 0.33 | 0.12 | 0.05 | 0.17 | 0.14 | 0.14 | 0.05 | 0.09 |
| BF and RF drift | | 0.02 | 0.01 | 0.17 | 0.03 | 0.14 | 0.26 | 0.59 | -0.07 |

Table 4.7.4. Mutation and drift by technique and time period.

The mutation fraction in our hydria sample is shown above in table 4.7.4 and in figure 4.7.4. As in other samples, the very small sample size and large number of motifs in the early black-figure periods gives an artificially high mutation fraction, which then falls to more reasonable levels once the sample size begins to grow. The mutation rate rises again during the red-figure periods, and remains very high throughout the sample, with only one red-figure period having less than 5% new motifs.

Rates of drift and mutation are compared in figures 4.7.5, 4.7.6 and 4.7.7. As figure 4.7.5 clearly illustrates, black-figure hydria were never at equilibrium. In the 575 - 525 and 550 - 500 date category, this was due to the mutation rate being very high, for reasons discussed above. The non-equilibrium of the 525 - 475 date category can be attributed to a reduction in sample size. When the sample size was reduced, many motifs were not copied, which produced a high rate of drift. In red-figure (figure 4.7.6), we see the same pattern we have seen in several other shape samples. Mutation begins very high and gradually decreases, while drift starts very low, reaches equilibrium in the 475 - 425 date category, then continues to rise as the sample size is reduced in size in the 450 - 400 and 425 - 375 date categories. When we look at both techniques together (figure 4.7.7), we see that from 550 BC onwards drift and mutation are never more than 14% apart, until the 425 - 375 date category. Because there are no black-figure hydria to balance the sample during this period, it retains its very high rate of drift.

### 4.7.2 Estimates of theta

The results of our calculations of theta for the hydria samples are shown in table 4.7.5 below and figures 4.7.8, 4.7.9 and 4.7.10. Estimates based on expectations of neutrality (tE) are consistently higher than values calculated for tF, indicating a possible bias towards conformity in this sample.

| | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 -375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|---|
| BF tE | | 5.172 | 27.239 | 36.355 | 23.437 | | | | | |
| BF tF | | 3.240 | 11.640 | 2.992 | 8.539 | | | | | |
| RF tE | | | | | 51.280 | 68.952 | 52.236 | 38.592 | 34.822 | 38.479 |
| RF tF | | | | | 11.214 | 24.095 | 35.621 | 14.748 | 5.380 | 2.837 |
| BF and RF tE | | 5.172 | 27.239 | 36.638 | 29.900 | 68.261 | 52.236 | 38.592 | 34.822 | 38.479 |
| BF and RF tF | | 3.240 | 11.640 | 3.076 | 9.619 | 23.777 | 35.621 | 14.748 | 5.380 | 2.837 |

Table 4.7.5. Estimates of theta.

| HYDRIA | SAMPLE | N | mu | 1% | 5% | 10% | tf-te at 5% level |
|---|---|---|---|---|---|---|---|
| BF | 575 - 525 | 117 | 0.33 | ACCEPT | ACCEPT | ACCEPT | |
| BF | 550 - 500 | 439 | 0.12 | ACCEPT | ACCEPT | ACCEPT | |
| BF | 525 - 475 | 187 | 0.03 | **REJECT** | **REJECT** | **REJECT** | less diverse |
| RF | 525 - 475 | 59 | 0.12 | **REJECT** | **REJECT** | **REJECT** | less diverse |
| RF | 500 - 450 | 206 | 0.18 | ACCEPT | ACCEPT | ACCEPT | |
| RF | 475 - 425 | 285 | 0.14 | ACCEPT | ACCEPT | ACCEPT | |
| RF | 450 - 400 | 207 | 0.14 | ACCEPT | ACCEPT | ACCEPT | |
| RF | 425 - 375 | 64 | 0.05 | **REJECT** | **REJECT** | **REJECT** | less diverse |
| RF | 400 - 300 | 137 | 0.09 | **REJECT** | **REJECT** | **REJECT** | less diverse |
| BF AND RF | 575 - 525 | 117 | 0.33 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 550 - 500 | 446 | 0.12 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 525 - 475 | 246 | 0.05 | **REJECT** | **REJECT** | **REJECT** | less diverse |
| BF AND RF | 500 - 450 | 216 | 0.17 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 475 - 425 | 285 | 0.14 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 450 - 400 | 207 | 0.14 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 425 - 375 | 64 | 0.05 | **REJECT** | **REJECT** | **REJECT** | less diverse |
| BF AND RF | 400 - 300 | 137 | 0.09 | **REJECT** | **REJECT** | **REJECT** | less diverse |

Table 4.7.6. Comparison of |tf-te| for model and data.

Comparison of our theta values with the model confirm that some periods are indeed less diverse than would be expected under the neutral model, but only a few. In both techniques as well as together, the hydria samples are less diverse than expected during the 525 - 475 date category. At the end of the red-figure sample, we also find that the 425 - 375 and 400 - 300 date categories reject the neutral model, again due to less than expected levels of diversity. In all other periods hydria do not reject the neutral model.

### 4.7.3 Power law distributions

We can compare these results with power law distributions of the decorative motifs present in each hydria sample. The r-squared values are shown in table 4.7.7 below and figure 4.7.12, as well as individually in figures 4.7.14, 4.7.15 and 4.7.16.

| | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 -375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|
| BF | | 0.974 | 0.978 | 0.902 | | | | | |
| RF | | | | 0.942 | 0.937 | 0.932 | 0.989 | 0.979 | 0.975 |
| BF and RF | | 0.974 | 0.978 | 0.945 | 0.956 | 0.932 | 0.989 | 0.979 | 0.975 |

Table 4.7.7. R-squared values.

| HYDRIA | SAMPLE | N | mu | 1% | 5% | 10% |
|---|---|---|---|---|---|---|
| BF | 575 - 525 | 117 | 0.33 | ACCEPT | ACCEPT | ACCEPT |
| BF | 550 - 500 | 439 | 0.12 | ACCEPT | ACCEPT | ACCEPT |
| BF | 525 - 475 | 187 | 0.03 | ACCEPT | ACCEPT | ACCEPT |
| RF | 525 - 475 | 59 | 0.12 | ACCEPT | ACCEPT | ACCEPT |
| RF | 500 - 450 | 206 | 0.18 | ACCEPT | **REJECT** | **REJECT** |
| RF | 475 - 425 | 285 | 0.14 | ACCEPT | **REJECT** | **REJECT** |
| RF | 450 - 400 | 207 | 0.14 | ACCEPT | ACCEPT | ACCEPT |
| RF | 425 - 375 | 64 | 0.05 | ACCEPT | ACCEPT | ACCEPT |
| RF | 400 - 300 | 137 | 0.09 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 575 - 525 | 117 | 0.33 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 550 - 500 | 446 | 0.12 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 525 - 475 | 246 | 0.05 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 500 - 450 | 216 | 0.17 | ACCEPT | ACCEPT | **REJECT** |
| BF AND RF | 475 - 425 | 285 | 0.14 | ACCEPT | **REJECT** | **REJECT** |
| BF AND RF | 450 - 400 | 207 | 0.14 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 425 - 375 | 64 | 0.05 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 400 - 300 | 137 | 0.09 | ACCEPT | ACCEPT | ACCEPT |

Table 4.7.8. R-squared values, model and data comparison

We compare these r-squared values to our model in table 4.7.8 above. All three of the black-figure samples are not rejected, but we can reject two of the red-figure date categories, 500 - 450 and 475 - 425. 475 - 425 is also rejected in the combined red-figure and black-figure sample.  Figure 4.7.15 shows that in the 500 - 450 date category, the second bin is far below the regression line, leading to a reduced r-squared value. A similar condition exists in the 525 - 475 date category, but this is not rejected by the r-squared test, due to the presence of the third bin above the line of regression, which balances the second bin's effects. When combined with black-figure, we see that the 500 - 450 date category does not reject the neutral model, due to the second bin being slightly closer to the regression line.

The 475 - 425 date category rejects the neutral model in both red-figure and in the combined sample, which is to be expected as there were no black-figure pots to add to the sample in this period. Once again we see fewer motifs than expected at the low end of the distribution, as shown by the points beneath the regression line. The high end of this distribution is also widely dispersed, leading to a reduced r-squared value overall.

| HYDRIA RESULTS | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| sample | test | 600-550 | 575-525 | 550-500 | 525-475 | 500-450 | 475-425 | 450-400 | 425-375 | 400-300 |
| BF | R-squared | | **0** | **0** | **0** | | | | | |
| | Theta | | **0** | **0** | **<** | | | | | |
| RF | R-squared | | | | **0** | **X** | **X** | **0** | **0** | **0** |
| | Theta | | | | **<** | **0** | **0** | **0** | **<** | **<** |
| BF and RF | R-squared | | **0** | **0** | **0** | **0** | **X** | **0** | **0** | **0** |
| | Theta | | **0** | **0** | **<** | **0** | **0** | **0** | **<** | **<** |

**0** = neutral model not rejected **X** = neutral model rejected by 5% r-squared test

**>** = more diverse at 5% theta test **<** = less diverse at 5% theta test

Table 4.7.9. Summary of results.

## 4.8 Pyxis

### 4.8.1 Description

For smaller objects, the Greeks used a variety of boxes. These include the pyxis and lekanis, which are combined in our study to form the pyxis sample. The pyxis is a clay copy of a shape usually made in boxwood (Boardman 2001: 261). These were small, lidded objects, with decoration around the sides or on the lid itself. The lekanis was a small lidded bowl. Its use is unclear, but it was probably used as a wedding vase in red-figure (Robertson 1992: 241).

| sample | shapes | N |
|---|---|---|
| Pyxis | | |
| | Pyxis | 449 |
| | Lekanis | 270 |

Table 4.8.1. Sample size

Table 4.8.1 shows the split between the two shapes. Both counts include the shapes themselves, as well as lids separate from complete shapes. Given that the figure decoration on both shapes may have been placed on the lid as well as the sides or interior, we have included them all together.

| | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 -375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|---|
| BF | 10 | 105 | 45 | 70 | 48 | 8 | 1 | 1 | 0 | 1 |
| RF | 0 | 0 | 2 | 0 | 10 | 17 | 94 | 124 | 47 | 136 |
| BF and RF | 10 | 105 | 47 | 70 | 58 | 25 | 95 | 125 | 47 | 137 |

Table 4.8.2. Sample size over time.

Our pyxis sample can be broken down by date as shown in table 4.8.2 and figure 4.8.1. Sample size overall is far smaller than in other shapes. The drop in sample size in the 425 - 375 date category also occurs in the pyxis sample, but there is an even larger drop in the 500 - 450 date category, a period in which the sample size of most shapes is quite large. The changes in sample size shown in figure 4.8.1 suggest that pyxis and lekanis shapes vanished from the record almost completely before being revived in red-figure in the 475 - 425 date category. The date category with the largest sample size is the last, 400 - 300.

| | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 -375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|---|
| BF new | 2 | 14 | 24 | 5 | 11 | 0 | 0 | 0 | 0 | 0 |
| BF total | 2 | 16 | 30 | 20 | 25 | 2 | 0 | 0 | 0 | 2 |
| RF new | 0 | 0 | 0 | 0 | 4 | 2 | 25 | 45 | 1 | 8 |
| RF total | 0 | 0 | 0 | 0 | 8 | 11 | 49 | 71 | 21 | 25 |
| BF and RF new | 2 | 14 | 24 | 5 | 15 | 2 | 25 | 45 | 1 | 8 |
| BF and RF total | 2 | 16 | 30 | 20 | 31 | 12 | 49 | 71 | 21 | 25 |

Table 4.8.3. New and total motifs.

Table 4.8.3 and figures 4.8.2 and 4.8.3 show changes in the number of motifs in use and the number of new motifs introduced during each period of the pyxis sample. As we have seen in other shapes, the number of motifs in each sample is strongly related to the sample size. However, the relatively large sample in the 400 - 300 date category is not matched by a large number of motifs. The greatest number of new motifs introduced in one period occurs in the red-figure 450 - 400 date category, and corresponds with an increase in sample size from the previous time step.

| | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 -375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|
| BF mu | 0.13 | 0.53 | 0.07 | 0.23 | | | | | |
| BF drift | 0.00 | 0.22 | 0.21 | 0.13 | | | | | |
| RF mu | | | | | | 0.27 | 0.36 | 0.02 | 0.06 |
| RF drift | | | | | | -0.14 | 0.19 | 1.09 | 0.03 |
| BF and RF mu | 0.13 | 0.51 | 0.07 | 0.26 | | 0.26 | 0.36 | 0.02 | 0.06 |
| BF and RF drift | 0.00 | 0.21 | 0.21 | 0.07 | | -0.13 | 0.18 | 1.09 | 0.03 |

Table 4.8.4. Mutation and drift by technique and time period.

Mutation and drift in the pyxis sample are shown in table 4. 8.4 and figures 4.8.4 to 4.8.7. Mutation varies greatly throughout the sample, given the small sample size for each period and the extensive fluctuation in the number of motifs introduced. In black-figure, drift and mutation are not closely matched, coming no closer than within 10% (figure 4.8.5). In red-figure (figure 4.8.6), drift and mutation nearly meet in the 400 - 300 date category, but are also mostly very far apart. Due to the almost total lack of overlap between the two samples, the joint sample (figure 4.8.7), shows no improvement. This indicates that our pyxis samples are not in a state of equilibrium, and therefore are more likely to reject the neutral model. However, given the very high mutation rates and small sample sizes of these data, it is difficult to predict the outcome of the tests.

### 4.8.2 Estimates of theta

Our estimates of theta for the pyxis samples are shown below in table 4. 8.5 and in figures 4.8.8 to 8.10.

| | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 -375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|---|
| BF tE | | 5.480 | 40.497 | 9.702 | 21.740 | | | | | |
| BF tF | | 2.382 | 5.959 | 28.167 | 13.400 | | | | | |
| RF tE | | | | | | | 41.987 | 69.903 | 15.132 | 9.243 |
| RF tF | | | | | | | 32.218 | 15.749 | 9.371 | 5.760 |
| BF and RF tE | | 5.480 | 36.780 | 9.702 | 27.810 | 9.679 | 41.368 | 68.980 | 15.132 | 9.208 |
| BF and RF tF | | 2.382 | 6.591 | 28.167 | 16.251 | 33.722 | 32.929 | 16.021 | 9.371 | 5.675 |

Table 4.8.5. Estimates of theta.

| PYXIS | SAMPLE | N | mu | 1% | 5% | 10% | tf-te at 5% level |
|---|---|---|---|---|---|---|---|
| BF | 600 - 550 | 105 | 0.13 | ACCEPT | ACCEPT | ACCEPT | |
| BF | 550 - 500 | 70 | 0.07 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| RF | 475 - 425 | 94 | 0.27 | ACCEPT | ACCEPT | ACCEPT | |
| RF | 450 - 400 | 124 | 0.36 | ACCEPT | ACCEPT | ACCEPT | |
| RF | 400 - 300 | 136 | 0.06 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 600 - 550 | 105 | 0.13 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 550 - 500 | 70 | 0.07 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| BF AND RF | 525 - 475 | 58 | 0.26 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 475 - 425 | 95 | 0.26 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 450 - 400 | 125 | 0.36 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 400 - 300 | 137 | 0.06 | ACCEPT | ACCEPT | ACCEPT | |

Table 4.8.6. Comparison of |tf-te| for model and data.

Table 4.8.6 shows the results of our comparison of the model and data. As can be seen, only the black-figure 550 - 500 date category and the corresponding joint sample is able to reject the neutral model, in the direction of greater than expected diversity. All other periods cannot reject the neutral model at any level, even 1%.

### 4.8.3 Power law distributions

The r-squared values of our data are shown below in table 4.8.7, and figure 4.8.12 . Individual power laws for all samples are shown in figures 4.8.14, 4.8.15 and 4.8.16.

| | 600-550 | 575-525 | 550-500 | 525-475 | 500-450 | 475-425 | 450-400 | 425-375 | 400-300 |
|---|---|---|---|---|---|---|---|---|---|
| BF | 0.948 | | 0.955 | | | | | | |
| RF | | | | | | 0.987 | 0.952 | | 0.90 |
| BF and RF | 0.948 | | 0.955 | 0.996 | | 0.987 | 0.952 | | 0.878 |

Table 4.8.7. R-squared values.

| PYXIS | SAMPLE | N | mu | 1% | 5% | 10% |
|---|---|---|---|---|---|---|
| BF | 600 - 550 | 105 | 0.13 | ACCEPT | ACCEPT | ACCEPT |
| BF | 550 - 500 | 70 | 0.07 | ACCEPT | ACCEPT | ACCEPT |
| RF | 475 - 425 | 94 | 0.27 | ACCEPT | ACCEPT | ACCEPT |
| RF | 450 - 400 | 124 | 0.36 | ACCEPT | ACCEPT | **REJECT** |
| RF | 400 - 300 | 136 | 0.06 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 600 - 550 | 105 | 0.13 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 550 - 500 | 70 | 0.07 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 525 - 475 | 58 | 0.26 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 475 - 425 | 95 | 0.26 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 450 - 400 | 125 | 0.36 | ACCEPT | ACCEPT | **REJECT** |
| BF AND RF | 400 - 300 | 137 | 0.06 | ACCEPT | ACCEPT | ACCEPT |

Table 4.8.8. R-squared values, model and data comparison

The results of our comparison of the model and data for all samples with n>50 are shown in table 4.8.8. As can be seen, at the 5% level, no sample is rejected. Despite the low sample size, the motifs used in our pyxis sample are distributed in accordance with the neutral model.

| PYXIS RESULTS | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| sample | test | 600-550 | 575-525 | 550-500 | 525-475 | 500-450 | 475-425 | 450-400 | 425-375 | 400-300 |
| BF | R-squared | **0** | | **0** | | | | | | |
| | Theta | **0** | | **>** | | | | | | |
| RF | R-squared | | | | | | **0** | **0** | | **0** |
| | Theta | | | | | | **0** | **0** | | **0** |
| BF and RF | R-squared | **0** | | **0** | **0** | | **0** | **0** | | **0** |
| | Theta | **0** | | **>** | **0** | | **0** | **0** | | **0** |

**0** = neutral model not rejected **X** = neutral model rejected by 5% r-squared test

**>** = more diverse at 5% theta test **<** = less diverse at 5% theta test

Table 4.8.9. Summary of results.

## 4.9 Plates

### 4.9.1 Description

Like the pots in the pyxis sample, plates are also very rare in the Beazley archive. They almost certainly have their source in other materials, in this case probably twisted reeds (Boardman 2001: 255), and for day to day use the original materials were probably preferred. A subtype of plates, known as fish plates, is also included in this sample. These are recognisable for their striking decorations depicting Mediterranean sea creatures.

| sample | shapes | N |
|---|---|---|
| Plates | | |
| | Plate | 335 |
| | Dish | 19 |

Table 4.9.1. Sample size

The sample size for plates is shown above in table 4.9.1. There are also 19 “dishes” included in this sample. These are apparently a slightly deeper form of plate, but the Beazley archive is not specific on this point.

| | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|---|
| BF | 1 | 21 | 36 | 61 | 37 | 10 | 0 | 1 | 0 | 0 |
| RF | 0 | 0 | 0 | 2 | 24 | 7 | 12 | 110 | 10 | 22 |
| BF and RF | 1 | 21 | 36 | 63 | 61 | 17 | 12 | 111 | 10 | 22 |

Table 4.9.2. Sample size over time.

The plates sample can be broken down by date as shown in table 4.9.2 and figure 4.9.1. The figure shows that there is one large sample of plates in the 450 - 400 date category, but that the rest of the samples are very small. In fact there are only three date categories which can be analysed using the techniques we have established, for which we have set a minimum reliable n of 50. Nonetheless it is worth looking briefly at the following analysis of motif frequencies on plates.

| | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|---|
| BF new | 0 | 7 | 25 | 8 | 1 | 0 | 0 | 0 | 0 | 0 |
| BF total | 0 | 7 | 27 | 17 | 11 | 6 | 0 | 0 | 0 | 0 |
| RF new | 0 | 0 | 0 | 1 | 13 | 1 | 5 | 5 | 1 | 6 |
| RF total | 0 | 0 | 0 | 3 | 25 | 2 | 7 | 15 | 4 | 14 |
| BF and RF new | 0 | 7 | 25 | 9 | 14 | 1 | 5 | 5 | 1 | 6 |
| BF and RF total | 0 | 7 | 27 | 18 | 29 | 7 | 7 | 15 | 4 | 14 |

Table 4.9.3. New and total motifs.

The number of motifs in use is shown above in table 4.9.3 and in figure 4.9.2. As figure 4.9.2 shows, the number of motifs in use peaks very early, in the black-figure 575 - 525 date category, and then declines. In red-figure, the peak is also very early, in the 525 - 475 date category, and then also declines, suggesting that early plates were decorated with a more diverse range of motifs than later plates. As figure 4.9.3 shows, a number of motifs were introduced alongside red-figure in the 525 - 475 date category, but very few were added after that.

| | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|
| BF mu | | 0.69 | 0.13 | 0.03 | | | | | |
| BF drift | | 0.14 | 0.30 | 0.19 | | | | | |
| RF mu | | | | | | | 0.05 | | |
| RF drift | | | | | | | -0.03 | | |
| BF and RF mu | | 0.69 | 0.14 | 0.23 | | | 0.05 | | |
| BF and RF drift | | 0.14 | 0.29 | 0.05 | | | -0.03 | | |

Table 4.9.4. Mutation and drift by technique and time period.

The mutation rate for plates is shown in figure 4.9.4 and in table 4.9.4 above. The mutation rates are high throughout. This is caused by the samples containing a very small number of plates between which to divide the new motifs which appear. When we compare rates of drift and mutation in figures 4.9.5 to 4.9.7, we see not only that there are very few samples which we can analyse, particularly in red-figure, but also that the samples which can be analysed are not generally at equilibrium. The only exception is the red-figure 450 - 400 date category and corresponding joint sample, in which drift and mutation are within 8% of one another. These are not encouraging figures, and as in the pyxis sample, given the erratic mutation rate caused by the tiny samples, we may not be able to reject the neutral model in many cases.

### 4.9.2 Estimates of theta

Our estimates of theta are shown below in table 4.9.5 and in figures 4.9.8 and 4.9.9. These results are compared with the model in table 4.9.6.

| | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|---|
| BF tE | | 4.070 | 50.736 | 8.153 | 5.649 | | | | | |
| BF tF | | 3.900 | 14.614 | 16.069 | 58.522 | | | | | |
| RF tE | | | | | | | | 4.901 | | |
| RF tF | | | | | | | | 94.276 | | |
| BF and RF tE | | 4.070 | 50.736 | 8.765 | 22.258 | | | 4.882 | | 17.606 |
| BF and RF tF | | 3.900 | 14.614 | 15.607 | 33.776 | | | 96.016 | | 8.132 |

Table 4.9.5. Estimates of theta.

| PLATES | SAMPLE | N | mu | 1% | 5% | 10% | tf-te at 5% level |
|---|---|---|---|---|---|---|---|
| BF | 550 - 500 | 61 | 0.13 | ACCEPT | ACCEPT | ACCEPT | |
| RF | 450 - 400 | 110 | 0.05 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| BF AND RF | 550 - 500 | 63 | 0.14 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 525 - 475 | 61 | 0.23 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 450 - 400 | 111 | 0.05 | **REJECT** | **REJECT** | **REJECT** | more diverse |

Table 4.9.6. Comparison of |tf-te| for model and data.

As can be seen from these results, the black-figure 550 - 500 date category does not reject the neutral model, nor does the corresponding joint sample or the following 525 - 475 date category joint sample, which can only be analysed when combined. The red-figure 450 - 400 date category rejects the neutral model across the board, and is more diverse than expected under the neutral model. The corresponding joint sample shows the same result.

### 4.9.3 Power law distributions

The results of the r-squared analysis of plates are shown below in table 4.9.7 and in figures 4.9.14 to 4.9.16. The r-squared values for the plates samples are very low, with the exception of the 450 - 400 date category.

| | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|
| BF | | | 0.351 | | | | | | |
| RF | | | | | | | 0.916 | | |
| BF and RF | | | 0.776 | 0.571 | | | 0.916 | | |

Table 4.9.7. R-squared values.

| PLATES | SAMPLE | N | mu | 1.00% | 5% | 10% |
|---|---|---|---|---|---|---|
| BF | 550 - 500 | 61 | 0.13 | **REJECT** | **REJECT** | **REJECT** |
| RF | 450 - 400 | 110 | 0.05 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 550 - 500 | 63 | 0.14 | **REJECT** | **REJECT** | **REJECT** |
| BF AND RF | 525 - 475 | 61 | 0.23 | **REJECT** | **REJECT** | **REJECT** |
| BF AND RF | 450 - 400 | 111 | 0.05 | ACCEPT | ACCEPT | ACCEPT |

Table 4.9.8. R-squared values, model and data comparison

The results of our comparison with the model and data are shown in table 4.9.8. As can be seen, only the 450 - 400 date category, both independently in red-figure and jointly, is not rejected. All other samples reject the neutral model at even the lowest level of significance.

| PLATES RESULTS | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| sample | test | 600-550 | 575-525 | 550-500 | 525-475 | 500-450 | 475-425 | 450-400 | 425-375 | 400-300 |
| BF | R-squared | | | **X** | | | | | | |
| | Theta | | | **0** | | | | | | |
| RF | R-squared | | | | | | | **0** | | |
| | Theta | | | | | | | **>** | | |
| BF and RF | R-squared | | | **X** | **X** | | | **0** | | |
| | Theta | | | **0** | **0** | | | **>** | | |

**0** = neutral model not rejected **X** = neutral model rejected by 5% r-squared test

**>** = more diverse at 5% theta test **<** = less diverse at 5% theta test

Table 4.9.9. Summary of results.

## 4.10 Ritual

### 4.10.1 Description

Ritual shapes is a catch all sample for the very lowest frequency shapes with a specific, non-symposium use. We include four distinct shapes in this sample, as shown in table 4.10.1. As with plates and the pyxis sample, even this aggregation leaves us with very little to analyse.

| sample | shapes | N |
|---|---|---|
| Ritual | | |
| | Nestoris | 1 |
| | Loutrophoros | 84 |
| | Lebes | 131 |
| | Phiale | 28 |

Table 4.10.1. Sample size

The single Nestoris (Beazley ref: 21338) in the sample refers to a South Italian shape. Its designation as an Athenian vase may well be an error on the part of the Beazely archive, but we do not have the means to evaluate this. The Loutrophoros shapes were a type of attenuated krater, primarily known through their use as offerings in Attic burials (Boardman 2004: 232). The Lebes was a larger shape, often on a stand, and was used for warming liquids, such as the bridal bath water (*ibid.*, p. 263). The phiale was a small shape apparently used for ritual libations rather than the drinking party (*ibid.*: 250). Each of these shapes were very different, but have been combined into one sample in order to see the effects of a specific context on motif frequency distribution.

| technique | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|---|
| BF | 0 | 10 | 11 | 33 | 15 | 2 | 0 | 0 | 0 | 0 |
| RF | 0 | 0 | 0 | 0 | 2 | 24 | 42 | 66 | 9 | 30 |
| BF and RF | 0 | 10 | 11 | 33 | 17 | 26 | 42 | 66 | 9 | 30 |

Table 4.10.2. Sample size over time.

The ritual sample is distributed by date as shown in table 4.10.2 and figure 4.10.1. Within this sample, there is only one period of sufficient size to analyse, the red-figure 450 - 400 date category, and the corresponding joint sample. Nonetheless we can see that sample size of ritual shapes increases steadily from the introduction of red-figure in the 525 - 475 date category to a peak in the 450 - 400 date category, and then collapses as in almost all other samples in the 425 - 375 date category, followed again by a small rise. In black-figure the peak occurs in the 550 - 500 date category.

| | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 -375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|---|
| BF new | 0 | 2 | 6 | 8 | 1 | 1 | 0 | 0 | 0 | 0 |
| BF total | 0 | 2 | 7 | 14 | 1 | 1 | 0 | 0 | 0 | 0 |
| RF new | 0 | 0 | 0 | 0 | 0 | 5 | 9 | 6 | 0 | 1 |
| RF total | 0 | 0 | 0 | 0 | 1 | 8 | 13 | 13 | 3 | 6 |
| BF and RF new | 0 | 2 | 6 | 8 | 1 | 6 | 9 | 6 | 0 | 1 |
| BF and RF total | 0 | 2 | 7 | 14 | 2 | 9 | 13 | 13 | 3 | 6 |

Table 4.10.3. New and total motifs in the cups sample.

The number of motifs in this tiny sample are shown in table 4.10.3 and figure 4.10.2. Despite being a smaller sample, there are actually more motifs present in the black-figure peak in the 550 - 500 date category than in the red-figure peak in the 450 - 400 date category. Despite being half again more numerous, the 450 - 400 date category has the same number of motifs overall. This tells us that the ritual shapes in red-figure may have been quite constrained in the types of motifs they featured, though it is difficult to draw conclusions from such small samples.

| | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 -375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|
| BF mu | | | 0.24 | | | | | | |
| BF drift | | | 0.03 | | | | | | |
| RF mu | | | | | | 0.21 | 0.09 | | 0.03 |
| RF drift | | | | | | 0.10 | 0.09 | | -0.07 |
| BF and RF mu | | | 0.24 | | | 0.21 | 0.09 | | 0.03 |
| BF and RF drift | | | 0.03 | | | 0.12 | 0.09 | | -0.07 |

Table 4.10.4. Mutation and drift by technique and time period.

Mutation rates are shown in table 4.10.4 and figure 4.10.4. The small sample size causes gaps in the calculations, as sample sizes in some date categories are too small to even calculate simple mutation. As with all of the smaller samples, mutation rates for date categories which can be calculated are very high. When we compare drift with mutation in figures 4.10.5 to 4.10.7, we see that they are very far apart, coming together only in red-figure the 450 - 400 date category, where they match exactly. Given that this is the only period which can be analysed in the ritual sample, we expect it to not reject the neutral model.

### 4.10.2 Estimates of theta

Estimates of theta are shown below in table 4.10.5 and in figures 4.10.8 to 4.10.10. Though we were able to calculate theta for many different periods, only the red-figure 450 - 400 date category and its corresponding joint sample could be compared with the model.

| | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 -375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|---|
| RF tE | | | | | | 4.595 | 6.815 | 5.106 | | 2.510 |
| RF tF | | | | | | 21.154 | 31.667 | 4.500 | | 0.544 |
| BF and RF tE | | | | 9.702 | | 5.287 | 6.815 | 5.106 | | 2.510 |
| BF and RF tF | | | | 26.225 | | 24.037 | 31.667 | 4.500 | | 0.544 |

Table 4.10.5. Estimates of theta.

| RITUAL | SAMPLE | N | mu | 1% | 5% | 10% | tf-te at 5% level |
|---|---|---|---|---|---|---|---|
| RF | 450 - 400 | 66 | 0.09 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 450 - 400 | 66 | 0.09 | ACCEPT | ACCEPT | ACCEPT | |

Table 4.10.6. Comparison of |tf-te| for model and data.

The result of this comparison is shown in table 4.10.6 above. As predicted, the sample does not reject the neutral model. Given that the sample is at equilibrium, this is the predicted result.

### 4.10.3 Power law distributions

The r-squared value for the single date category which can be analysed is shown below. This result is compared with the model in table 4.10.8.

| | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|
| BF | | | | | | | | | |
| RF | | | | | | | 0.78 | | |
| BF and RF | | | | | | | 0.78 | | |

Table 4.10.7. R-squared values

| RITUAL | SAMPLE | N | mu | 1% | 5% | 10% |
|---|---|---|---|---|---|---|
| RF | 450 - 400 | 66 | 0.09 | **REJECT** | **REJECT** | **REJECT** |
| BF AND RF | 450 - 400 | 66 | 0.09 | **REJECT** | **REJECT** | **REJECT** |

Table 4.10.8. R-squared values, model and data comparison

As can be seen, the r-square test rejects the neutral model for this sample at every level. This sample simply does not form a good power law, given the uneven distribution of motif bins throughout.

| RITUAL RESULTS | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| sample | test | 600-550 | 575-525 | 550-500 | 525-475 | 500-450 | 475-425 | 450-400 | 425-375 | 400-300 |
| RF | R-squared | | | | | | | **X** | | |
| | Theta | | | | | | | **0** | | |
| BF and RF | R-squared | | | | | | | **X** | | |
| | Theta | | | | | | | **0** | | |

**0** = neutral model not rejected **X** = neutral model rejected by 5% r-squared test

**>** = more diverse at 5% theta test **<** = less diverse at 5% theta test

Table 4.10.9. Summary of results.

## 4.11 All shapes

### 4.11.1 Description

After considering each group of shapes independently, we can now consider all of the shapes together as one large sample. The tests in this section will determine the overall pattern of motif distributions across all shapes.

| sample | N |
|---|---|
| Pyxis | 719 |
| Skyphos | 2339 |
| Cups | 7128 |
| Lekythoi | 12335 |
| Plates | 354 |
| Ritual | 244 |
| Amphorae | 7358 |
| Hydria | 1740 |
| Oinochoe | 3258 |
| Krater | 3232 |

Table 4.11.1. Sample size

Table 4.11.1 shows the contribution each of the previous sections makes to the overall sample. As can be seen, the lekythoi sample, is much larger than the other samples, and represents 31.9% of the total. Therefore the greater than expected levels of diversity observed in this sample, particularly in red-figure lekythoi, may influence the results overall.

| | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 -375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|---|
| BF | 61 | 621 | 2308 | 6523 | 7811 | 1530 | 101 | 15 | 31 | 60 |
| RF | 0 | 1 | 7 | 99 | 1421 | 4168 | 6633 | 3995 | 1134 | 2501 |
| BF and RF | 61 | 622 | 2315 | 6622 | 9232 | 5698 | 6734 | 4010 | 1165 | 2561 |

Table 4.11.2. Sample size over time.

Sample size over time is shown above in table 4.11.2 and in figure 4.11.2. As can be seen, the sample peaks during the 525 - 475 date category, with 9232 vases, the same period during which the red-figure technique was developed. This was, however, not the period with the greatest number of motifs in circulation (table 4.11.3 and figure 4.11.2). This was the red-figure 475 - 425 date category, the date category which also saw the greatest absolute number of motifs introduced (figure 4.11.3).

| | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 -375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|---|
| BF new | 11 | 54 | 105 | 75 | 62 | 11 | 0 | 0 | 0 | 3 |
| BF total | 11 | 61 | 157 | 192 | 212 | 108 | 15 | 4 | 9 | 19 |
| RF new | 0 | 0 | 0 | 8 | 40 | 64 | 121 | 108 | 5 | 13 |
| RF total | 0 | 0 | 1 | 42 | 142 | 241 | 323 | 284 | 113 | 132 |
| BF and RF new | 11 | 54 | 105 | 79 | 90 | 72 | 121 | 108 | 5 | 16 |
| BF and RF total | 11 | 61 | 157 | 197 | 248 | 261 | 323 | 284 | 114 | 138 |

Table 4.11.3. New and total motifs.

| | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 -375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|
| BF mu | 0.09 | 0.05 | 0.01 | 0.01 | 0.01 | 0.00 | | 0.00 | 0.05 |
| BF drift | 0.01 | 0.00 | 0.01 | 0.01 | 0.08 | 0.92 | | -0.16 | -0.12 |
| RF mu | | | 0.08 | 0.03 | 0.02 | 0.02 | 0.03 | 0.00 | 0.01 |
| RF drift | | | -0.33 | -0.04 | -0.01 | 0.01 | 0.04 | 0.16 | 0.00 |
| BF and RF mu | 0.09 | 0.05 | 0.01 | 0.01 | 0.01 | 0.02 | 0.03 | 0.00 | 0.01 |
| BF and RF drift | 0.01 | 0.00 | 0.01 | 0.00 | 0.01 | 0.01 | 0.04 | 0.15 | 0.00 |

Table 4.11.4. Mutation and drift by technique and time period.

Figure 4.11.4 and table 4.11.4 show the mutation rate for the all shapes sample. As we have seen in the individual shape samples, the mutation rate is very high initially, as many motifs enter the system in the first two black-figure date categories. It then declines until red-figure is introduced and peaks again in the 450 - 400 date category, before dropping off during the sample size collapse of the 425 - 375 date category, before rising slightly again. The black-figure mutation rate rockets up to 5% in the final 400 - 300 date category, but when we combine the samples we see that this is almost entirely due to red-figure motifs appearing in black-figure for the first time.

Table 4.11.4 and figures 4.11.5 to 4.11.7 show that levels of mutation and drift are nearly balanced throughout, especially in the middle of each sample (the 525 - 475 and 475 - 425 date categories) when the sample size is largest. At each end of each sample, the mutation and drift rates are farther apart, and therefore less likely to conform to the neutral model. At the beginning of the samples, mutation is high, while at the end, rates of drift become extremely high due to the large number of motifs not being copied.

4.11.2 Calculations of theta.

Calculations for theta for the overall sample are shown below in table 4.11.5 and in figures 4.11.8 to 4.11.10. Even by combining all of the shape samples, there were still too few black-figure pots in the 450 - 400 date category to reliably calculate theta and make a comparison. Though we do have theta estimates for the red-figure 550 - 500 date category, this sample was not used in tests against the model because there was no prior period from which to calculate the mutation rate.

| | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 -375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|---|
| BF tE | 4.161 | 16.945 | 38.262 | 37.219 | 40.307 | 26.679 | 5.091 | | 4.604 | 9.965 |
| BF tF | 28.768 | 14.098 | 18.274 | 8.979 | 8.568 | 33.438 | 207.184 | | 15.860 | 0.800 |
| RF tE | | | | 28.070 | 39.455 | 55.818 | 71.169 | 70.056 | 31.401 | 29.837 |
| RF tF | | | | 10.163 | 18.784 | 45.598 | 55.005 | 70.660 | 31.250 | 12.144 |
| BF and RF tE | 4.161 | 16.935 | 38.225 | 38.282 | 47.019 | 56.573 | 70.871 | 69.973 | 31.468 | 31.372 |
| BF and RF tF | 28.768 | 14.146 | 18.370 | 9.034 | 10.006 | 46.671 | 56.287 | 70.997 | 31.493 | 12.121 |

Table 4.11.5. Estimates of theta.

| ALL | SAMPLE | N | mu | 1% | 5% | 10% | tf-te at 5% level |
|---|---|---|---|---|---|---|---|
| BF | 600 - 550 | 621 | 0.09 | ACCEPT | ACCEPT | ACCEPT | |
| BF | 575 - 525 | 2308 | 0.05 | ACCEPT | ACCEPT | ACCEPT | |
| BF | 550 - 500 | 6523 | 0.01 | ACCEPT | **REJECT** | **REJECT** | less diverse |
| BF | 525 - 475 | 7811 | 0.01 | ACCEPT | **REJECT** | **REJECT** | less diverse |
| BF | 500 - 450 | 1530 | 0.01 | ACCEPT | ACCEPT | ACCEPT | |
| BF | 475 - 425 | 101 | 0.00 | **REJECT** | **REJECT** | **REJECT** | more diverse |
| BF | 400 - 300 | 60 | 0.05 | **REJECT** | **REJECT** | **REJECT** | less diverse |
| RF | 525 - 475 | 1421 | 0.03 | ACCEPT | **REJECT** | **REJECT** | less diverse |
| RF | 500 - 450 | 4168 | 0.02 | ACCEPT | ACCEPT | ACCEPT | |
| RF | 475 - 425 | 6633 | 0.02 | ACCEPT | ACCEPT | ACCEPT | |
| RF | 450 - 400 | 3995 | 0.03 | ACCEPT | ACCEPT | ACCEPT | |
| RF | 425 - 375 | 1134 | 0.00 | ACCEPT | ACCEPT | ACCEPT | |
| RF | 400 - 300 | 2501 | 0.01 | ACCEPT | **REJECT** | **REJECT** | less diverse |
| BF AND RF | 600 - 550 | 622 | 0.09 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 575 - 525 | 2315 | 0.05 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 550 - 500 | 6622 | 0.01 | ACCEPT | **REJECT** | **REJECT** | less diverse |
| BF AND RF | 525 - 475 | 9232 | 0.01 | ACCEPT | **REJECT** | **REJECT** | less diverse |
| BF AND RF | 500 - 450 | 5698 | 0.01 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 475 - 425 | 6734 | 0.02 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 450 - 400 | 4010 | 0.03 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 425 - 375 | 1165 | 0.00 | ACCEPT | ACCEPT | ACCEPT | |
| BF AND RF | 400 - 300 | 2561 | 0.01 | ACCEPT | **REJECT** | **REJECT** | less diverse |

Table 4.11.6. Comparison of |tf-te| for model and data.

The overall results for theta for all shapes are shown in table 4.11.6 above. The results show that overall, 3 out of 7 date categories of black-figure pots fail to reject the neutral model. Black-figure pots begin neutral, then become less diverse than expected during the periods of maximum sample size, then become neutral again, then more diverse than expected, then for the final date category less diverse again.

In red-figure, during its first phase of production in the 525 - 475 date category, we see that diversity was less than expected under the neutral model. Then there are four date categories in which the neutral model is not rejected, lasting from 500 to 375 BC. The final date category is also less diverse than expected.

When we combine the results for the BF and RF sample, we see the same results, with the exception that the tiny but more diverse black-figure 475 - 425 date category is completely swamped by the corresponding large red-figure sample, with the result that the neutral model is not rejected. We still see less diversity than expected in the 550 - 500 and 525 - 475 date categories, as well as in the final 400 - 300 date category.

### 4.11.3 Power law distributions

We can now compare these results with the results of our power law tests for the overall sample. The r-squared values for each date category in the overall sample are shown in table 4.11.7 below and in figure 4.11.12. The individual power laws are shown in figures 4.11.14 to 4.11.16. The large sample sizes have resulted in very high r-squared values.

| | 600-550 | 575-525 | 550-500 | 525-475 | 500-450 | 475-425 | 450-400 | 425-375 | 400-300 |
|---|---|---|---|---|---|---|---|---|---|
| BF | 0.935 | 0.946 | 0.983 | 0.989 | 0.977 | | | | 0.833 |
| RF | | | | 0.983 | 0.994 | 0.991 | 0.995 | 0.965 | 0.997 |
| BF and RF | 0.935 | 0.946 | 0.986 | 0.987 | 0.995 | 0.991 | 0.995 | 0.967 | 0.996 |

Table 4.11.7. R-squared values.

| ALL | SAMPLE | N | mu | 1% | 5% | 10% |
|---|---|---|---|---|---|---|
| BF | 600 - 550 | 621 | 0.09 | ACCEPT | **REJECT** | **REJECT** |
| BF | 575 - 525 | 2308 | 0.05 | ACCEPT | ACCEPT | ACCEPT |
| BF | 550 - 500 | 6523 | 0.01 | ACCEPT | ACCEPT | ACCEPT |
| BF | 525 - 475 | 7811 | 0.01 | ACCEPT | ACCEPT | ACCEPT |
| BF | 500 - 450 | 1530 | 0.01 | ACCEPT | ACCEPT | ACCEPT |
| BF | 475 - 425 | 101 | 0.00 | ACCEPT | ACCEPT | ACCEPT |
| BF | 400 - 300 | 60 | 0.05 | ACCEPT | ACCEPT | **REJECT** |
| RF | 525 - 475 | 1421 | 0.03 | ACCEPT | ACCEPT | ACCEPT |
| RF | 500 - 450 | 4168 | 0.02 | ACCEPT | ACCEPT | ACCEPT |
| RF | 475 - 425 | 6633 | 0.02 | ACCEPT | ACCEPT | ACCEPT |
| RF | 450 - 400 | 3995 | 0.03 | ACCEPT | ACCEPT | ACCEPT |
| RF | 425 - 375 | 1134 | 0.00 | ACCEPT | ACCEPT | ACCEPT |
| RF | 400 - 300 | 2501 | 0.01 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 600 - 550 | 622 | 0.09 | ACCEPT | **REJECT** | **REJECT** |
| BF AND RF | 575 - 525 | 2315 | 0.05 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 550 - 500 | 6622 | 0.01 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 525 - 475 | 9232 | 0.01 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 500 - 450 | 5698 | 0.01 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 475 - 425 | 6734 | 0.02 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 450 - 400 | 4010 | 0.03 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 425 - 375 | 1165 | 0.00 | ACCEPT | ACCEPT | ACCEPT |
| BF AND RF | 400 - 300 | 2561 | 0.01 | ACCEPT | ACCEPT | ACCEPT |

Table 4.11.8. R-squared values, model and data comparison

We compare the results of these r-squared values with the results of our model in table 4.11.8 above. As can be seen, in only the first black-figure test can we reject the neutral model at the 5% level of significance. In every other date category, the r-squared values for our data are greater than those for the model. We therefore conclude that according to this method for evaluating real world data against the neutral model, the distribution of motifs on Greek figure-painted pottery does not reject the neutral model.

| ALL SHAPES RESULTS | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| sample | test | 600-550 | 575-525 | 550-500 | 525-475 | 500-450 | 475-425 | 450-400 | 425-375 | 400-300 |
| BF | R-squared | **X** | **0** | **0** | **0** | **0** | **0** | | | **0** |
| | Theta | **0** | **0** | **<** | **<** | **0** | **<** | | | **<** |
| RF | R-squared | | | | **0** | **0** | **0** | **0** | **0** | **0** |
| | Theta | | | | **<** | **0** | **0** | **0** | **0** | **<** |
| BF and RF | R-squared | **X** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** |
| | Theta | **0** | **0** | **<** | **<** | **0** | **0** | **0** | **0** | **<** |

**0** = neutral model not rejected **X** = neutral model rejected by 5% r-squared test

**>** = more diverse at 5% theta test **<** = less diverse at 5% theta test

Table 4.11.9. Summary of results.

## 4.12 Summary and discussion

### 4.12.1 Theta results

| | | | |
|---|---|---|---|
| BF Neutral | 21 | | |
| BF Not Neutral | 20 | 9 more diverse | 11 less diverse |
| RF Neutral | 25 | | |
| RF Not Neutral | 26 | 17 more diverse | 10 less diverse |
| BF and RF Neutral | 46 | | |
| BF and RF Not Neutral | 32 | 20 more diverse | 12 less diverse |

Table 4.12.1 Theta results at the 5% level.

As table 4.12.1 shows, when we consider all of the results across all shape samples, we see almost exactly equal numbers of samples which reject and which do not reject the neutral model in the separate black figure and red figure samples. However, in the combined black figure and red figure samples, we see that there are 46 samples (59%) which do not reject the neutral model and 32 (41%) which do reject the neutral model. It should be noted that there are nearly equal numbers of black figure pots (19,061) in the sample as red figure pots (19,959), but these are distributed very unevenly over time (table 4.11.2, above).

Of the samples which are not neutral, roughly equal numbers of black figure individual samples are more diverse (43%) as are less diverse (57%). In red figure, the non-neutral samples tend to be more diverse than expected, with 63% more diverse and 37% less diverse. In the combined sample we see almost exactly the same split, with two thirds

(62.5%) of non-neutral cases are more diverse than expected, and one third (37.5%) less diverse than expected under the neutral model.

4.12.2 R-squared results

| | |
|---|---|
| BF Neutral | 34 |
| BF Not Neutral | 7 |
| RF Neutral | 44 |
| RF Not Neutral | 8 |
| BF and RF Neutral | 64 |
| BF and RF Not Neutral | 14 |

Table 4.12.2 R-squared results at the 5% level.

Our r-squared results overall are very different. Table 4.12.2 shows that at the 5% level of significance, nearly all of our samples across all techniques failed to reject the neutral model. A higher proportion of black figure samples (17%) were able to reject the neutral model than red figure samples (15%). In the combined sample 18% of samples were rejected. When compared to the rejection rate of 41% for the theta test in the combined sample, we see that the r-squared test has comparatively little power to reject the neutral model. However, it also shows that the motifs in 82% of the combined samples are distributed according to a power law, in which a handful of motifs are many times more popular than all of the rest of the motifs (though not as popular as they would be under conditions of conformity).

4.12.3 Results by date

We can also consider the above results by their individual date category, as shown below:

| Technique | Date category | Result | | Of those not neutral | | % Neutral |
|---|---|---|---|---|---|---|
| | | Neutral | Not Neutral | More Diverse | Less Diverse | |
| BF | 600 - 550 | 4 | 2 | 2 | 0 | 66.7% |
| BF | 575 - 525 | 7 | 0 | 0 | 0 | 100.0% |
| BF | 550 - 500 | 6 | 4 | 2 | 2 | 60.0% |
| BF | 525 - 475 | 3 | 5 | 0 | 5 | 37.5% |
| BF | 500 - 450 | 1 | 5 | 3 | 2 | 16.7% |
| BF | 475 - 425 | 0 | 2 | 2 | 0 | 0.0% |
| BF | 400 - 300 | 0 | 2 | 0 | 2 | 0.0% |
| RF | 525 - 475 | 3 | 4 | 1 | 3 | 42.9% |
| RF | 500 - 450 | 6 | 2 | 2 | 0 | 75.0% |
| RF | 475 - 425 | 6 | 3 | 3 | 0 | 66.7% |
| RF | 450 - 400 | 6 | 5 | 4 | 1 | 54.5% |
| RF | 425 - 375 | 1 | 7 | 5 | 2 | 12.5% |
| RF | 400 - 300 | 3 | 6 | 2 | 4 | 33.3% |
| BF and RF | 600 - 550 | 4 | 2 | 2 | 0 | 66.7% |
| BF and RF | 575 - 525 | 7 | 0 | 0 | 0 | 100.0% |
| BF and RF | 550 - 500 | 6 | 4 | 2 | 2 | 60.0% |
| BF and RF | 525 - 475 | 6 | 4 | 0 | 4 | 60.0% |
| BF and RF | 500 - 450 | 6 | 2 | 2 | 0 | 75.0% |
| BF and RF | 475 - 425 | 6 | 3 | 3 | 0 | 66.7% |
| BF and RF | 450 - 400 | 6 | 5 | 4 | 1 | 54.5% |
| BF and RF | 425 - 375 | 1 | 7 | 5 | 2 | 12.5% |
| BF and RF | 400 - 300 | 4 | 5 | 2 | 3 | 44.4% |

Table 4.12.3 Theta results for all samples.

Table 4.12.3 shows the combined results of the theta test for all shape samples, by date. Early black figure samples rejected the neutral model the fewest times, especially the 575 - 525 date category, in which 100% of the samples did not reject the neutral model. Later black figure (from 525 BC onwards) rejects the neutral model in nearly all cases, but there were far fewer samples to test. In red figure, the early periods are also the most neutral, with 75% of samples failing to reject the neutral model in the 500 - 450 date category. The later date categories, 425 - 375 and 400 - 300, reject the neutral model in a majority of cases.

When the samples are combined, these trends hold. From 600 to 400 BC, a majority of samples do not reject the neutral model. It is only in the 425 - 375 and 400 - 300 date categories that the situation reverses. As we have seen in the individual samples, there was a sharp reduction in sample size in the 425 - 375 date category, which caused non-neutral levels of diversity in many samples. Sample size recovers somewhat during the 400 - 300 date category, but diversity remains both higher and lower than expected.

Table 4.12.4 below shows the r-squared results for all samples. Here we see trends in opposition to our theta results. According to our r-squared tests, the early samples rejected the neutral model more times than the later samples, with early black figure being the least likely to conform to a power law and later red figure the most likely. The difference between the two sets of results can be seen clearly in table 4.12.5 below.

| Technique | Date category | Neutral | Not Neutral | % Neutral |
|---|---|---|---|---|
| BF | 600 - 550 | 2 | 4 | 33.3% |
| BF | 575 - 525 | 6 | 1 | 85.7% |
| BF | 550 - 500 | 8 | 2 | 80.0% |
| BF | 525 - 475 | 8 | 0 | 100.0% |
| BF | 500 - 450 | 6 | 0 | 100.0% |
| BF | 475 - 425 | 2 | 0 | 100.0% |
| BF | 400 - 300 | 2 | 0 | 100.0% |
| RF | 525 - 475 | 6 | 1 | 85.7% |
| RF | 500 - 450 | 6 | 2 | 75.0% |
| RF | 475 - 425 | 8 | 1 | 88.9% |
| RF | 450 - 400 | 9 | 2 | 81.8% |
| RF | 425 - 375 | 7 | 1 | 87.5% |
| RF | 400 - 300 | 9 | 0 | 100.0% |
| BF and RF | 600 - 550 | 2 | 4 | 33.3% |
| BF and RF | 575 - 525 | 6 | 1 | 85.7% |
| BF and RF | 550 - 500 | 8 | 2 | 80.0% |
| BF and RF | 525 - 475 | 9 | 1 | 90.0% |
| BF and RF | 500 - 450 | 8 | 0 | 100.0% |
| BF and RF | 475 - 425 | 8 | 1 | 88.9% |
| BF and RF | 450 - 400 | 9 | 2 | 81.8% |
| BF and RF | 425 - 375 | 6 | 2 | 75% |
| BF and RF | 400 - 300 | 9 | 0 | 100.0% |

Table 4.12.4 R-squared results for all samples

| Technique | Date category | Theta Neutral | R Squared Neutral |
|---|---|---|---|
| BF | 600 - 550 | 66.7% | 33.3% |
| BF | 575 - 525 | 100.0% | 85.7% |
| BF | 550 - 500 | 60.0% | 80.0% |
| BF | 525 - 475 | 37.5% | 100.0% |
| BF | 500 - 450 | 16.7% | 100.0% |
| BF | 475 - 425 | 0.0% | 100.0% |
| BF | 400 - 300 | 0.0% | 100.0% |
| RF | 525 - 475 | 42.9% | 85.7% |
| RF | 500 - 450 | 75.0% | 75.0% |
| RF | 475 - 425 | 66.7% | 88.9% |
| RF | 450 - 400 | 54.5% | 81.8% |
| RF | 425 - 375 | 12.5% | 87.5% |
| RF | 400 - 300 | 33.3% | 100.0% |
| BF and RF | 600 - 550 | 66.7% | 33.3% |
| BF and RF | 575 - 525 | 100.0% | 85.7% |
| BF and RF | 550 - 500 | 60.0% | 80.0% |
| BF and RF | 525 - 475 | 60.0% | 90.0% |
| BF and RF | 500 - 450 | 75.0% | 100.0% |
| BF and RF | 475 - 425 | 66.7% | 88.9% |
| BF and RF | 450 - 400 | 54.5% | 81.8% |
| BF and RF | 425 - 375 | 12.5% | 75% |
| BF and RF | 400 - 300 | 44.4% | 100.0% |

Table 4.12.5 Comparison of Theta and R-squared results. Percentage shows cases which did not reject the neutral model.

### 4.12.4 Results by shape

Finally, we can examine our results by shape, as shown below in table 4.12.6. For each shape, we see the number of samples which reject or fail to reject the neutral model, along with the direction of non-neutrality where appropriate. The percentage of samples which do not reject the neutral model is also shown for ease of interpretation.

The table shows a roughly even split between neutral and non-neutral samples within each shape, with the mean percentage of cases rejecting the neutral model at 56.5%. However, we do see some noteworthy exceptions. In cups (section 4.1 above) and skyphoi (section 4.2), we see an even split between neutral and non neutral samples. Of those samples which are not neutral, we see that all are more diverse than expected. In oinochoe (section 4.3), we see a similar split, but with slightly more cases not rejecting the neutral model. Of the two black figure oinochoe samples which reject the neutral model, both are less diverse than expected, while the 2 red figure samples which reject the neutral model are more diverse than expected. In kraters (section 4.4), we again see a division between neutral and non-neutral samples similar to that found in oinochoe, but this time all the non-neutral samples are less diverse than expected. Lekythoi (section 4.5), are the least neutral of all our samples. Of the majority of these samples which are not neutral, all are more diverse than expected. Amphorae (section 4.6) reject the neutral model in a third of cases in both red figure and black figure, but this climbs to over half when the two techniques are combined. Black figure amphorae are less diverse than expected, while red figure and the combined sample are equally split between greater and lesser diversity. Hydria (section 4.7) show a very similar pattern of results to oinochoe and kraters, in that they are half to two-thirds neutral, while those hydria samples which are not neutral are less diverse than expected. Pyxis, plate and ritual shape samples (sections 4.8 to 4.10) almost universally fail to reject the neutral model, and in the few cases in which they do reject the neutral model they do so in the direction of greater than expected diversity. Finally, we see that in the overall sample (section 4.11), most black figure samples reject the neutral model, while most red figure and joint samples do not reject. Of those samples which do reject the neutral model, all but one are less diverse than expected.

| | Neutral | Not Neutral | Less diverse | More diverse | %Neutral |
|---|---|---|---|---|---|
| CUPS | | | | | |
| BF | 2 | 3 | 0 | 3 | 40.0% |
| RF | 3 | 3 | 0 | 3 | 50.0% |
| BF AND RF | 4 | 5 | 0 | 5 | 44.4% |
| SKYPHOS | | | | | |
| BF | 3 | 2 | 0 | 2 | 60.0% |
| RF | 3 | 3 | 0 | 3 | 50.0% |
| BF AND RF | 5 | 4 | 0 | 4 | 55.6% |
| WINE JUG | | | | | |
| BF | 2 | 2 | 2 | 0 | 50.0% |
| RF | 3 | 2 | 0 | 2 | 60.0% |
| BF AND RF | 5 | 3 | 1 | 2 | 62.5% |
| WINE MIXING | | | | | |
| BF | 2 | 1 | 1 | 0 | 66.7% |
| RF | 3 | 3 | 3 | 0 | 50.0% |
| BF AND RF | 5 | 3 | 3 | 0 | 62.5% |
| OIL | | | | | |
| BF | 2 | 3 | 1 | 2 | 40.0% |
| RF | 0 | 6 | 0 | 6 | 0.0% |
| BF AND RF | 3 | 5 | 0 | 5 | 37.5% |
| STORAGE | | | | | |
| BF | 2 | 4 | 4 | 0 | 33.3% |
| RF | 2 | 4 | 2 | 2 | 33.3% |
| BF AND RF | 5 | 4 | 2 | 2 | 55.6% |
| WATER JUG | | | | | |
| BF | 2 | 1 | 1 | 0 | 66.7% |
| RF | 3 | 3 | 3 | 0 | 50.0% |
| BF AND RF | 5 | 3 | 3 | 0 | 62.5% |
| BOXES | | | | | |
| BF | 1 | 1 | 0 | 1 | 50.0% |
| RF | 3 | 0 | 0 | 0 | 100.0% |
| BF AND RF | 5 | 1 | 0 | 1 | 83.3% |
| PLATES | | | | | |
| BF | 1 | 0 | 0 | 0 | 100.0% |
| RF | 0 | 1 | 0 | 1 | 0.0% |
| BF AND RF | 2 | 1 | 0 | 1 | 66.7% |
| RITUAL | | | | | |
| RF | 1 | 0 | 0 | 0 | 100.0% |
| BF AND RF | 1 | 0 | 0 | 0 | 100.0% |
| ALL | | | | | |
| BF | 3 | 4 | 3 | 1 | 42.9% |
| RF | 4 | 2 | 2 | 0 | 66.7% |
| BF AND RF | 6 | 3 | 3 | 0 | 66.7% |

Table 4.12.6 Theta results at 5% for each shape.

### 4.12.5 Discussion

The results for all neutral model tests have been compiled in table 12.7 for tests of diversity using estimates of theta and table 12.8 for tests of distribution using r-squared values. As we have discussed in the main results, because the r-squared and theta tests measure different aspects of each sample, the results do not always agree. Because it is a more sensitive test, we use the theta results in the discussion which follows as the primary means of judging whether the neutral model has been rejected.

In some date categories we see that all shape samples reject the neutral model. These include 425 to 375, in which all shapes reject the neutral model (though the overall sample in 425 to 375 does not reject the neutral model) and the last phase of large scale black-figure production (500 to 450) in which all shape samples reject the neutral model, with the exception of plates (though again the overall sample does not reject the neutral model). In both 425 to 375 in red-figure and 500 to 450 in black-figure, the sample size for every shape was reduced from the levels found in the previous date category. This had the effect of significantly increasing the number of motifs that were not copied, as we have seen in each individual drift/mutation comparison throughout our results. This caused the neutral model to be rejected, as the diversity of these samples became either more or less than what would be expected under neutrality, depending on the mutation rate, sample size and how the motifs in each sample were distributed. From this result we conclude that we should expect to reject the neutral model when the sample size is significantly reduced. This would help explain the many rejections of the neutral model in 450 to 400 (oinochoe, kraters, lekythoi and amphorae), as sample sizes here are much smaller than those found in 475 to 425.

In addition to this tendency, we also see that some shape samples reject the neutral model in the first date category in which the shape appears. In black-figure this effect is seen in cups and skyphoi in 600 to 550, while in red-figure the neutral model is rejected in lekythoi, amphorae, hydria and all shapes in 525 to 475. Our r-squared results (table 12.8) also show that in 600 to 550 we find the most rejections which occur in a single date category. These results suggest that we should also expect to reject the neutral model at the beginning of a series, though because it does not affect all shapes, this effect is not as strong as the effect seen at the end of a series.

| BLACK FIGURE RESULTS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 600-550 | 575-525 | 550-500 | 525-475 | 500-450 | 475-425 | 450-400 | 425-375 | 400-300 |
| CUPS | > | 0 | > | 0 | > | | | | |
| SKYPHOS | > | 0 | 0 | 0 | > | | | | |
| OINOCHOE | 0 | | 0 | < | < | | | | |
| KRATER | | 0 | 0 | < | | | | | |
| LEKYTHOI | | 0 | 0 | 0 | > | > | | | |
| AMPHORAE | 0 | 0 | < | < | < | | | | < |
| HYDRIA | | 0 | 0 | < | | | | | |
| PYXIS | 0 | | > | | | | | | |
| RITUAL | | | | | | | | | |
| PLATES | | | 0 | | | | | | |
| ALL | 0 | 0 | < | < | 0 | > | | | < |

| RED FIGURE RESULTS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 600-550 | 575-525 | 550-500 | 525-475 | 500-450 | 475-425 | 450-400 | 425-375 | 400-300 |
| CUPS | | | | 0 | 0 | > | 0 | > | > |
| SKYPHOS | | | | 0 | > | > | 0 | > | 0 |
| OINOCHOE | | | | | 0 | 0 | > | > | 0 |
| KRATER | | | | 0 | 0 | 0 | < | < | < |
| LEKYTHOI | | | | > | > | > | > | > | > |
| AMPHORAE | | | | < | 0 | 0 | > | > | < |
| HYDRIA | | | | < | 0 | 0 | 0 | < | < |
| PYXIS | | | | | | 0 | 0 | | 0 |
| RITUAL | | | | | | | 0 | | |
| PLATES | | | | | | | > | | |
| ALL | | | | < | 0 | 0 | 0 | 0 | < |

| BLACK FIGURE AND RED FIGURE RESULTS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 600-550 | 575-525 | 550-500 | 525-475 | 500-450 | 475-425 | 450-400 | 425-375 | 400-300 |
| CUPS | > | 0 | > | 0 | 0 | > | 0 | > | > |
| SKYPHOS | > | 0 | 0 | 0 | > | > | 0 | > | 0 |
| OINOCHOE | 0 | | 0 | < | 0 | 0 | > | > | 0 |
| KRATER | | 0 | 0 | 0 | 0 | 0 | < | < | < |
| LEKYTHOI | | 0 | 0 | 0 | > | > | > | > | > |
| AMPHORAE | 0 | 0 | < | < | 0 | 0 | > | > | 0 |
| HYDRIA | | 0 | 0 | < | 0 | 0 | 0 | < | < |
| PYXIS | 0 | | > | 0 | | 0 | 0 | | 0 |
| RITUAL | | | | | | | 0 | | |
| PLATES | | | 0 | 0 | | | > | | |
| ALL | 0 | 0 | < | < | 0 | 0 | 0 | 0 | < |

0 = neutral > = more diverse at 5% theta test < = less diverse at 5% theta test

Table 4.12.7 Overall results.

| BLACK FIGURE RESULTS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 600-550 | 575-525 | 550-500 | 525-475 | 500-450 | 475-425 | 450-400 | 425-375 | 400-300 |
| CUPS | **X** | 0 | 0 | 0 | 0 | | | | |
| SKYPHOS | 0 | **X** | 0 | 0 | 0 | | | | |
| OINOCHOE | **X** | | 0 | 0 | 0 | | | | |
| KRATER | | 0 | **X** | 0 | | | | | |
| LEKYTHOI | | 0 | 0 | 0 | 0 | 0 | | | |
| AMPHORAE | **X** | 0 | 0 | 0 | 0 | | | | 0 |
| HYDRIA | | 0 | 0 | 0 | | | | | |
| PYXIS | 0 | | 0 | | | | | | |
| RITUAL | | | | | | | | | |
| PLATES | | | **X** | | | | | | |
| ALL | **X** | 0 | 0 | 0 | 0 | 0 | | | 0 |

| RED FIGURE RESULTS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 600-550 | 575-525 | 550-500 | 525-475 | 500-450 | 475-425 | 450-400 | 425-375 | 400-300 |
| CUPS | | | | 0 | 0 | 0 | 0 | 0 | 0 |
| SKYPHOS | | | | 0 | **X** | 0 | **X** | 0 | 0 |
| OINOCHOE | | | | | 0 | 0 | 0 | 0 | 0 |
| KRATER | | | | **X** | 0 | 0 | 0 | 0 | 0 |
| LEKYTHOI | | | | 0 | 0 | 0 | 0 | **X** | 0 |
| AMPHORAE | | | | 0 | 0 | 0 | 0 | 0 | 0 |
| HYDRIA | | | | 0 | **X** | **X** | 0 | 0 | 0 |
| PYXIS | | | | | | 0 | 0 | | 0 |
| RITUAL | | | | | | | **X** | | |
| PLATES | | | | | | | 0 | | |
| ALL | | | | 0 | 0 | 0 | 0 | 0 | 0 |

| BLACK FIGURE AND RED FIGURE RESULTS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 600-550 | 575-525 | 550-500 | 525-475 | 500-450 | 475-425 | 450-400 | 425-375 | 400-300 |
| CUPS | **X** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SKYPHOS | 0 | **X** | 0 | 0 | 0 | 0 | **X** | 0 | 0 |
| OINOCHOE | **X** | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| KRATER | | 0 | **X** | 0 | 0 | 0 | 0 | 0 | 0 |
| LEKYTHOI | | 0 | 0 | 0 | 0 | 0 | 0 | **X** | 0 |
| AMPHORAE | **X** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| HYDRIA | | 0 | 0 | 0 | 0 | **X** | 0 | 0 | 0 |
| PYXIS | 0 | | 0 | 0 | | 0 | 0 | | 0 |
| RITUAL | | | | | | | **X** | | |
| PLATES | | | **X** | **X** | | | 0 | | |
| ALL | **X** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

0 = neutral model not rejected at 5%    **X** = neutral model rejected at 5%

Table 4.12.8 Overall results – R-squared test.

The combined black-figure and red-figure results show that the effects described above are cancelled out in some cases in the date categories which overlap (525 to 475 and 500 to 450). For example, cups in black-figure in 500 to 450 are more diverse than expected in black-figure, but do not reject the neutral model in red-figure in the same date category. When the two samples are combined, they also do not reject the neutral model. This tells us that the size of the black-figure shape samples is not enough to change the result of the larger red-figure sample for the same date category. This shows that a subset of a larger sample can reject the neutral model, despite the overall sample not rejecting the neutral model. Examples of this are found throughout our results. This shows that results may change depending on the scale of resolution used in assessing whether or not to reject the neutral model.

In some cases, however, we reject the neutral model in black-figure and red-figure separately and in the combined sample. Shapes which show this effect include amphorae and hydria in 525 to 475 and skyphoi and lekythoi in 500 to 450. This shows us that the same effects were felt in each technique, and that these were not resolved differently in the combined sample. Though some of the above effects may be the result of small sample sizes, in the two cases mentioned above the sample sizes were large and not radically different from previous samples.

When all of these effects are taken into consideration, we see that there is a tendency in our samples of figure-painted pottery to reject the neutral model at times when sample sizes change.[7] This effect is by no means universal, as cups, skyphoi and hydria do not reject the neutral model in 450 to 400. It does suggest though, that the neutral model may be less likely to apply in cases of change and transition. This means that the process by which motifs are copied and invented is different during periods of transition than it is during periods of stability.

We know of no other test of the neutral model based on samples which include changes such as the move to red-figure from black-figure, so we cannot speculate whether this is a feature of figure-painted pottery specifically or of cultural transmission of neutral variants generally. However, a tendency to change the process by which variants are copied during times of change does fit with some previous analysis, such as that by Fitzhugh (2001). His analysis shows that in times of environmental uncertainty the costs of individual invention are lower, as it becomes less clear whom to copy for a successful

7 It would be interesting to see if this effect could be eliminated by creating equal sized random samples from each date category in each shape.

outcome. If such increases in individual invention were not matched by an equivalent level of drift (that is, motifs not copied from the previous date category), then we would tend to see an increase in diversity. This is confirmed by our results. From 500 BC onwards, those samples which reject the neutral model tend to do so in the direction of greater than expected diversity.

In contrast, in 525 to 475, when the transition to red-figure was taking place, we see that the black-figure samples which reject the neutral model do so in the direction of reduced diversity. This could indicate a greater reliance on copying and less individual invention. Many new techniques are in use at this time, red-figure among them, and it may be that in 525 to 475, the attention of painters had shifted away from motifs and towards techniques as the primary area in which to compete. We will explore this hypothesis further in chapter 6.

Additionally, there are shapes which defy all of these patterns. These include cups, skyphoi and lekythoi. In all samples, cups and skyphoi either do not reject the neutral model or are more diverse than expected. As above, an excess of diversity indicates greater preference for low frequency variants, including, potentially, those that have just been invented. Yet we cannot explain these results as being due to transitions or changes in the wider pot economy, as cups and skyphoi reject the neutral model during periods in which other shapes show signs of stability (550 to 500 (cups only), 500 to 450 (skyphoi only) and 475 to 425 (both)). Therefore it may have been the case that an excess of diversity was the norm for these shapes, and that the samples which do not reject the neutral model are the exception. As personal drinking vessels, cups and skyphoi may have been more "personalised" than other shapes, and thereby painters may have been encouraged to produce more variation in designs for them. However, if we disregard the first sample (600 to 550) and 425 to 375 (in which all samples reject the neutral model), we see that in 4 out of 7 samples, cups do not reject the neutral model, and in 5 out of 7 cases skyphoi do not reject the neutral model. Therefore, preference for novelty was a factor in a minority of samples.

This would not, however, explain the preference for novelty seen in lekythoi. From 500 to 450 onwards, all lekythoi samples, whether black-figure or red-figure, reject the neutral model and are more diverse than expected. This suggests that there was something very different about the use or manufacture of lekythoi after 500 BC. In addition to red-figure, another technique, known as white ground, was also introduced around this time. This involved the application of a chalky white slip onto the surface of the pot, on which figures were then painted with a brush. Given its fragility, white ground was used predominantly for dedication purposes and funerals. After 500 BC, both our black-figure and red-figure lekythoi samples contain a very large proportion of white ground vases. The process by which motifs were copied and invented in this technique may have been different than for black-figure or red-figure. We would need to repeat our analysis with the white ground vases treated separately to find out if this was the case.[8]

It may also be the case that the use of lekythoi as funerary offerings influenced the process by which motifs were chosen. White ground lekythoi with funerary iconography were the most favoured offering to the dead from the 460s to around 410 BC (Kurtz 1975: 133-136). This "fashion", as Kurtz describes it (Kurtz 1975: xix), was due to "restrictions on more extravagant forms of Athenian funerary art which seem to have been in effect from around 500 BC to some time in the third quarter of the fifth century " (Kurtz 1975: 136). The evidence for specific legislation forbidding the use of extravagant funeral displays  is somewhat slim, and is mostly inferred from "the absence of impressive private grave monuments with fine sculptural decoration from Athenian cemeteries during most of the fifth century"(*ibid.*). If lekythoi served as a replacement for these more elaborate displays of wealth in funerary contexts, then we may expect to find higher than expected levels of diversity, as competition could lead to a preference for novelty in iconography. In fact, this is exactly what our results show. From 500 BC onwards, all lekythoi samples, in both black figure and red figure, are more diverse than expected. This indicates a preference for novel iconographical variants. Kurtz observes that "the Athenian tendency towards extravagance in funerary art...must have been greatly frustrated by these restrictions" (*ibid.*). Our results indicate that this tendency may have been redirected to lekythoi. If lekythoi had been used simply to commemorate the dead with some appropriate stock iconography, then we would expect to see less diversity than expected.[9]

In the smaller individual samples, ritual, pyxides and plates, all samples which could be analysed either do not reject the neutral model or are more diverse than expected. Given that these shapes were more unusual and would often be purchased for special purposes, we would expect to find more diversity than predicted by the neutral model. In fact it is surprising that more of these shape samples do not reject the neutral model.

8 We will explore techniques and the transition from black-figure to red-figure fully in chapters 6 and in the fourth part of chapter 7.

9 As can be readily observed in modern cemeteries.

We conclude that random copying explains much of the observed variation in motifs used in figure-painted pottery. During periods of transition and in periods of declining sample size, however, the neutral model is not always sufficient as an explanation for observed variation. Furthermore, in some shapes, especially red-figure lekythoi, the process by which motifs were chosen seems to have favoured greater levels of diversity than predicted by the neutral model. We hypothesise that these shapes were more subject to individual preference than other shapes, and that this affected diversity even at the aggregate level. These results show that we should be extremely cautious about applying any sort of narrative, whether political or psychological, to what is essentially a random process. We do not deny that individual factors played a part in the personal decisions that went into choosing motifs for use on figure-painted pottery, but our results show that in most cases these aggregate into pure random choice. For example, the theory of an increase in individualism as a result of changes in politics (Neer 2002) is compatible with our results as a proximate description of the types of motifs which are popular in the 5$^{th}$ century, but such theories do not describe the source of variation, which is, as we have shown, the process of copying itself.

These results may be easier to understand in the context of individual motifs rather than overall samples, though of course at this point we can only assess each sample as a whole, not where each motif in each sample stands in relation to the results. In the next chapter we will explore the individual proportions of motifs, including their variability and turnover rate, and will show how these can help us to understand our main results, as well as reveal some motifs with very unusual frequencies which require further explanation. We will also perform another test of the neutral model based on turnover rate alone, in order to confirm our results for r-squared and theta based tests of the neutral model.

# Chapter 5

# Motifs

## Proportions, shapes and turnover

### 5.1 Motif proportions

#### 5.1.1 Motif proportions overall

Our first analysis examines the changing frequencies of popular motifs. In tables 5.1 to 5.3, we see the 20 highest frequency motifs in each date category in black-figure, red-figure and both together, across all shapes. The tables also show the percentage each motif makes up of all the motifs observed in that date category and technique. In some date categories there were not enough motifs to make a list of the 20 most frequent, due to small sample size, so we have calculated the popularity of the motifs that were present. Where motifs have the same proportion, such as Paris and Poseidon in black-figure in 600 to 550, we have listed them in descending order by sample size.

Tables 5.1 to 5.3 clearly show that in each date category, the frequency of the most common motif is many orders of magnitude greater than the frequency of the 20th most common motif. For example, in black-figure in 500 to 450, we see that the most popular motif (Dionysos) makes up 12.9% of all measured motifs, while the 20th most popular motif (Iolaos) makes up only 0.9%. In fact, in each sample, the ten highest frequency motifs alone (a mere 1.5% of the 665 motifs recorded) make up a majority of all motifs observed in each date category. Of all 665 motifs recorded, the "top ten" make up 73.9% of the total sum of motifs in observed black-figure, 61.2% in red-figure, and 65% in the combined black-figure and red-figure sample. Our results have confirmed the expectations of Bentley *et. al.* (2004) by demonstrating that such highly skewed distributions are characteristic of the neutral model.[10] We hypothesise that this is due to the "rich get richer" phenomenon (Newman 2005: 348), in which variants are copied in proportion to the number of copies of that variant which already exist. This means that each existing copy of the Dionysos motif made further copies that much more likely. As Newman's review shows (Newman 2005), this phenomenon describes the behaviour of a very wide range of observed distributions, including the population of cities, the sales of popular books, and as, our study shows, the distribution of motifs on Greek figure-painted pottery.

Such systems are not immune to change. A high frequency variant is likely to remain so, but change occurs because each time a copy is made there is also the possibility of innovation. It is possible by chance alone for a newly introduced variant to be copied in ever greater numbers until it too reaches a high frequency. A good example of this is the motif Eros, which as table 5.2 shows, makes up only 1.1% of all red-figure motifs in 500 to 450 but goes on to become the highest frequency motif from 450 to 400 onwards. The neutral model was not rejected for the  samples of all shapes during which this change occurred, from 500 to 450 to 425 to 375. Therefore, while it is possible that the rise in popularity of Eros is due to factors external to the process of copying itself (such as some form of  external influence), the evidence demonstrates that overall during these periods we do not

10 However, we do not yet have a test with enough statistical power to reject any but the most extreme non-neutral distributions. Measurement of diversity, as we have seen, is a much more sensitive test.

| Black figure | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 625 - 575 | | 600 - 550 | | 575 - 525 | | 550 - 500 | | 525 - 475 | | 500 - 450 | | 475 - 425 | | 450 - 400 | | 425 - 375 | | 400 - 300 | |
| Siren | 43.5 | Siren | 34.1 | Warrior | 15.6 | Warrior | 12.7 | Dionysos | 12.9 | Dionysos | 10.3 | Warrior | 17.4 | Athena | 40.0 | Satyr | 26.3 | Athlete | 26.0 |
| Sphinx | 17.4 | Sphinx | 22.9 | Horsemen | 7.5 | Dionysos | 9.4 | Maenad | 11.4 | Maenad | 10.1 | Athlete | 13.0 | Athlete | 20.0 | Athlete | 21.1 | Athena | 24.0 |
| Achilles | 4.3 | Warrior | 7.5 | Sphinx | 6.9 | Satyr | 9.4 | Satyr | 11.4 | Athena | 9.5 | Judge | 13.0 | Horsemen | 20.0 | Nike | 10.5 | Nike | 23.1 |
| Ajax | 4.3 | Horsemen | 6.4 | Herakles | 6.8 | Herakles | 8.2 | Warrior | 10.3 | Warrior | 8.1 | Athena | 8.7 | Trainer | 20.0 | Athena | 10.5 | Judge | 4.8 |
| Apollo | 4.3 | Herakles | 3.2 | Siren | 6.7 | Maenad | 7.5 | Herakles | 8.2 | Satyr | 8.0 | Aktaion | 4.3 | | | Maenad | 10.5 | Triptolemos | 2.9 |
| Bellerophon | 4.3 | Hermes | 1.9 | Satyr | 5.2 | Athena | 7.0 | Athena | 5.8 | Herakles | 7.2 | Apollo | 4.3 | | | Dionysos | 5.3 | Hoplitodromoi | 2.9 |
| Horsemen | 4.3 | Achilles | 1.6 | Athena | 4.7 | Hermes | 4.5 | Goddess | 3.8 | Goddess | 5.2 | Artemis | 4.3 | | | Ploutos | 5.3 | Victor | 2.9 |
| Warrior | 4.3 | Satyr | 1.3 | Dionysos | 3.7 | Horsemen | 3.9 | Hermes | 2.9 | Apollo | 3.5 | Dionysos | 4.3 | | | Diskoboloi | 5.3 | Eirene | 1.9 |
| Griffin | 4.3 | Memnon | 1.1 | Athlete | 3.2 | Athlete | 2.7 | Apollo | 2.6 | Hermes | 3.3 | Eros | 4.3 | | | Judge | 5.3 | Ploutos | 1.9 |
| Pegasoi | 4.3 | Athlete | 1.1 | Hermes | 3.2 | Apollo | 2.7 | Sphinx | 2.0 | Sphinx | 2.7 | Herakles | 4.3 | | | | | Aphrodite | 1.0 |
| Satyr | 4.3 | Dionysos | 0.8 | Maenad | 2.6 | Archer | 2.1 | Horsemen | 2.0 | Horsemen | 2.5 | Huntsmen | 4.3 | | | | | Demeter | 1.0 |
| | | Zeus | 0.8 | Theseus | 1.4 | Goddess | 1.6 | Athlete | 1.9 | Giant | 1.7 | Trainer | 4.3 | | | | | Eros | 1.0 |
| | | Maenad | 0.8 | Zeus | 1.4 | Siren | 1.5 | Amazon | 1.5 | Amazon | 1.6 | Pegasoi | 4.3 | | | | | Herakles | 1.0 |
| | | Artemis | 0.5 | Minotaur | 1.3 | Iolaos | 1.5 | Giant | 1.4 | Nereid | 1.5 | Victor | 4.3 | | | | | Olympias | 1.0 |
| | | Calydonian | 0.5 | Achilles | 1.2 | Sphinx | 1.3 | Ariadne | 1.3 | Peleus | 1.4 | Satyr | 4.3 | | | | | Persephone | 1.0 |
| | | Deianeira | 0.5 | Apollo | 1.1 | Ariadne | 1.2 | Archer | 1.1 | Thetis | 1.3 | | | | | | | Boxer | 1.0 |
| | | Nereus | 0.5 | Iolaos | 1.0 | Achilles | 1.1 | Peleus | 1.1 | Pegasoi | 1.2 | | | | | | | Pankratists | 1.0 |
| | | Nessos | 0.5 | Goddess | 0.9 | Giant | 1.0 | Achilles | 1.1 | Athlete | 1.0 | | | | | | | Trainer | 1.0 |
| | | Paris | 0.5 | Nessos | 0.9 | Artemis | 0.9 | Thetis | 1.0 | Achilles | 0.9 | | | | | | | Griffin | 1.0 |
| | | Poseidon | 0.5 | Ariadne | 0.8 | Ajax | 0.8 | Nereid | 0.9 | Iolaos | 0.9 | | | | | | | | |

Table 5.1. Top 20 motifs by date. Black figure, all shapes. First column in each date range shows the most popular motifs in descending order. The second column shows the percentage of that motif out of the sum of motifs observed in that date range.

| Red figure | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 550 - 500 | | 525 - 475 | | 500 - 450 | | 475 - 425 | | 450 - 400 | | 425 - 375 | | 400 - 300 | |
| Satyr | 11.9 | Warrior | 13.7 | Satyr | 9.6 | Nike | 12.6 | Eros | 9.3 | Eros | 15.3 | Eros | 13.2 |
| Warrior | 7.5 | Satyr | 12.8 | Maenad | 7.7 | Satyr | 8.8 | Satyr | 9.2 | Satyr | 9.4 | Satyr | 11.5 |
| Athena | 6.7 | Athlete | 11.6 | Warrior | 7.1 | Maenad | 8.7 | Athlete | 7.9 | Maenad | 8.2 | Maenad | 11.2 |
| Dionysos | 6.0 | Maenad | 6.3 | Athlete | 6.9 | Warrior | 6.3 | Maenad | 6.9 | Nike | 6.3 | Athlete | 10.6 |
| Herakles | 6.0 | Dionysos | 4.6 | Nike | 6.4 | Athlete | 6.2 | Warrior | 5.3 | Athlete | 6.0 | Dionysos | 7.7 |
| Maenad | 6.0 | Herakles | 4.2 | Dionysos | 4.9 | Dionysos | 3.9 | Nike | 5.2 | Dionysos | 5.2 | Griffin | 6.8 |
| Athlete | 5.2 | Diskoboloi | 4.1 | Athena | 2.8 | Eros | 3.1 | Apollo | 3.2 | Sphinx | 4.3 | Erotes | 3.7 |
| Apollo | 4.5 | Acontist | 2.9 | Trainer | 2.4 | Athena | 2.3 | Dionysos | 2.9 | Hermes | 4.2 | Nike | 3.4 |
| Achilles | 3.7 | Archer | 2.8 | Herakles | 2.4 | Eos | 2.2 | Erotes | 2.2 | Aphrodite | 4.1 | Aphrodite | 3.0 |
| Ajax | 3.7 | Athena | 2.4 | Zeus | 2.4 | Apollo | 2.1 | Charon | 2.1 | Athena | 2.7 | Amazon | 2.4 |
| Artemis | 3.7 | Trainer | 2.1 | Theseus | 2.1 | Hermes | 2.0 | Hermes | 2.1 | Herakles | 2.2 | Hermes | 2.3 |
| Leto | 2.2 | Horsemen | 2.0 | Archer | 1.9 | Theseus | 1.9 | Sphinx | 2.0 | Erotes | 1.7 | Ariadne | 2.0 |
| Acontist | 2.2 | Hoplitodromoi | 1.7 | Hermes | 1.8 | Artemis | 1.9 | Aphrodite | 1.7 | Apollo | 1.6 | Warrior | 1.9 |
| Diskoboloi | 2.2 | Hermes | 1.6 | Apollo | 1.7 | Zeus | 1.4 | Theseus | 1.6 | Paris | 1.3 | Herakles | 1.8 |
| Archer | 2.2 | Apollo | 1.3 | Acontist | 1.6 | Goddess | 1.4 | Athena | 1.6 | Warrior | 1.3 | Athena | 1.2 |
| Pegasoi | 2.2 | Amazon | 1.2 | Poseidon | 1.5 | Tithonos | 1.3 | Artemis | 1.5 | Trainer | 1.2 | Apollo | 1.2 |
| Ariadne | 1.5 | Theseus | 1.1 | Diskoboloi | 1.3 | King | 1.3 | Amazon | 1.3 | Amazon | 1.2 | Poseidon | 0.8 |
| Hektor | 1.5 | Nike | 1.1 | Artemis | 1.2 | Herakles | 1.0 | Herakles | 1.2 | Artemis | 1.0 | Pan | 0.7 |
| Iolaos | 1.5 | Achilles | 0.9 | Eros | 1.1 | Trainer | 1.0 | Acontist | 1.2 | Goddess | 1.0 | Demeter | 0.7 |
| Hetaira | 1.5 | Poseidon | 0.9 | Eos | 1.1 | Acontist | 1.0 | Muse | 1.1 | Ariadne | 0.8 | Goddess | 0.7 |

Table 5.2. Top 20 motifs by date. Red figure, all shapes.

| Black figure and red figure | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 625 - 575 | | 600 - 550 | | 575 - 525 | | 550 - 500 | | 525 - 475 | | 500 - 450 | | 475 - 425 | | 450 - 400 | | 425 - 375 | | 400 - 300 | |
| Siren | 43.5 | Siren | 34.1 | Warrior | 15.6 | Warrior | 12.6 | Dionysos | 12.0 | Satyr | 9.2 | Nike | 12.5 | Eros | 9.3 | Eros | 15.0 | Eros | 12.7 |
| Sphinx | 17.4 | Sphinx | 22.9 | Horsemen | 7.5 | Satyr | 9.5 | Satyr | 11.6 | Maenad | 8.3 | Satyr | 8.8 | Satyr | 9.2 | Satyr | 9.8 | Athlete | 11.2 |
| Achilles | 4.3 | Warrior | 7.5 | Sphinx | 6.9 | Dionysos | 9.4 | Maenad | 10.8 | Warrior | 7.4 | Maenad | 8.7 | Athlete | 7.9 | Maenad | 8.3 | Satyr | 11.0 |
| Ajax | 4.3 | Horsemen | 6.4 | Herakles | 6.8 | Herakles | 8.2 | Warrior | 10.7 | Dionysos | 6.3 | Warrior | 6.3 | Maenad | 6.9 | Nike | 6.4 | Maenad | 10.8 |
| Apollo | 4.3 | Herakles | 3.2 | Siren | 6.7 | Maenad | 7.5 | Herakles | 7.8 | Athlete | 5.4 | Athlete | 6.2 | Warrior | 5.3 | Athlete | 6.4 | Dionysos | 7.4 |
| Bellerophon | 4.3 | Hermes | 1.9 | Satyr | 5.2 | Athena | 7.0 | Athena | 5.4 | Nike | 4.9 | Dionysos | 3.9 | Nike | 5.2 | Dionysos | 5.2 | Griffin | 6.6 |
| Horsemen | 4.3 | Achilles | 1.6 | Athena | 4.7 | Hermes | 4.4 | Goddess | 3.4 | Athena | 4.5 | Eros | 3.1 | Apollo | 3.2 | Sphinx | 4.2 | Nike | 4.1 |
| Warrior | 4.3 | Satyr | 1.3 | Dionysos | 3.7 | Horsemen | 3.9 | Athlete | 3.0 | Herakles | 3.7 | Athena | 2.3 | Dionysos | 2.9 | Hermes | 4.1 | Erotes | 3.5 |
| Griffin | 4.3 | Memnon | 1.1 | Athlete | 3.2 | Athlete | 2.8 | Hermes | 2.7 | Hermes | 2.2 | Apollo | 2.1 | Erotes | 2.2 | Aphrodite | 4.0 | Aphrodite | 2.9 |
| Pegasoi | 4.3 | Athlete | 1.1 | Hermes | 3.2 | Apollo | 2.7 | Apollo | 2.5 | Apollo | 2.2 | Eos | 2.1 | Charon | 2.1 | Athena | 2.8 | Amazon | 2.3 |
| Satyr | 4.3 | Dionysos | 0.8 | Maenad | 2.6 | Archer | 2.1 | Horsemen | 2.0 | Goddess | 2.0 | Hermes | 2.0 | Hermes | 2.1 | Herakles | 2.1 | Hermes | 2.2 |
| | | Zeus | 0.8 | Theseus | 1.4 | Goddess | 1.6 | Sphinx | 1.9 | Trainer | 1.9 | Theseus | 1.9 | Sphinx | 2.0 | Erotes | 1.7 | Athena | 2.1 |
| | | Maenad | 0.8 | Zeus | 1.4 | Siren | 1.5 | Amazon | 1.4 | Zeus | 1.8 | Artemis | 1.9 | Aphrodite | 1.7 | Apollo | 1.5 | Ariadne | 1.9 |
| | | Artemis | 0.5 | Minotaur | 1.3 | Iolaos | 1.5 | Giant | 1.3 | Theseus | 1.7 | Zeus | 1.4 | Athena | 1.7 | Paris | 1.3 | Herakles | 1.8 |
| | | Calydonian | 0.5 | Achilles | 1.2 | Sphinx | 1.3 | Archer | 1.3 | Archer | 1.7 | Goddess | 1.4 | Theseus | 1.6 | Warrior | 1.3 | Warrior | 1.8 |
| | | Deianeira | 0.5 | Apollo | 1.1 | Ariadne | 1.2 | Ariadne | 1.1 | Acontist | 1.2 | Tithonos | 1.3 | Artemis | 1.5 | Trainer | 1.2 | Apollo | 1.1 |
| | | Nereus | 0.5 | Iolaos | 1.0 | Achilles | 1.1 | Achilles | 1.0 | Poseidon | 1.2 | King | 1.3 | Amazon | 1.3 | Amazon | 1.2 | Poseidon | 0.8 |
| | | Nessos | 0.5 | Goddess | 0.9 | Artemis | 1.0 | Peleus | 1.0 | Horsemen | 1.1 | Herakles | 1.1 | Herakles | 1.2 | Artemis | 0.9 | Demeter | 0.7 |
| | | Paris | 0.5 | Nessos | 0.9 | Giant | 1.0 | Thetis | 0.9 | Artemis | 1.1 | Trainer | 1.0 | Acontist | 1.2 | Goddess | 0.9 | Pan | 0.7 |
| | | Poseidon | 0.5 | Ariadne | 0.8 | Ajax | 0.9 | Nereid | 0.9 | Diskoboloi | 0.9 | Acontist | 1.0 | Muse | 1.1 | Ariadne | 0.8 | Goddess | 0.7 |

Table 5.3. Top 20 motifs by date. Black figure and red figure, all shapes.

detect bias or novelty seeking, and therefore the rise in popularity of Eros could be due to a process of random copying alone.[11] The system works both ways, as motifs can also fail to be copied. As the proportion of a motif drops so too does the likelihood that it will be copied further. This is illustrated in the frequencies of the motif "warrior" in table 5.3. After rising in frequency in the first two date categories, warriors are the highest frequency motif in 575 to 525 (15.6%) and 550 to 500 (12.6%), but then fall in proportion until 400 to 300, by which time the motif makes up only 1.8% of all observed motifs.

But perhaps this change from warrior to Eros was the result of some shift in preference in motifs on figure-painted pottery. As tables 5.1 to 5.3 show, it is undeniable that a change in the "character" of popular motifs took place halfway through our samples. In the first four date categories (625 to 500), we see that "archaic" motifs such as sirens, sphinxes, warriors and horsemen dominate, while in the last five date categories (500 to 300), more "Dionysiac" motifs are popular, such as satyrs, maenads, Dionysos and Eros. This change has been widely noted (e.g. Shapiro 1990), and is often described as a reflection of wider political events (Neer 2002). We do not dispute that this change took place, but we contend that it may be unnecessary to ascribe changes in motif frequency to the actions of politically attuned painters. It is only possible to see a purpose in such changes in motif frequencies retrospectively, and without reference to quantitative data it is difficult to tell whether explanations are being revealed or imposed.

When viewing the outcomes of such processes, it is a natural human reaction to ascribe a narrative to observations. Popular books remain popular because they are "better" books, larger cities remain large because they are better places to live. Yet, would we also ascribe such intentionality to the intensity of solar flares, the magnitude of earthquakes or the size of forest fires? It is easy to accept that systems with no human involvement can be governed by stochastic processes, but when people are involved and make choices, we often seek to ascribe some form of intentionality to their behaviour. Yet, as has been shown in the choice of dog breeds (Herzog *et. al.* 2004) and baby names (Hahn and Bentley 2003), at the population level there is no basis for doing so, except in exceptional circumstances such as the correlation between registrations of dalmatians and the release of Disney's *101 Dalmatians* (Herzog *et. al.* 2004).

11 We will explore the popularity of Eros later in our discussion.

In these systems, each variant is neutral in comparison to each other, but all variants as a whole can be selected in favour of some other variant (Bentley *et. al.* 2007: 157).[12] In our figure-painted pottery samples, each motif variant is equivalent, but figures themselves have clearly been selected in favour of the purely geometric decoration which preceded figure-painted pottery. Within the range of variants available, the neutral model cannot be rejected in 6 out of 9 of the overall samples shown in table 5.3. This does not mean that each painter did not care about what he painted, nor does it mean that the painter literally blindly chose from a list of possibilities, any more than the names we are given are randomly chosen from phone books. It simply means that when all of these choices are combined, the aggregate result is indistinguishable from a system of random copying, as shown by our computer model.[13]

This model is by no means meant to diminish the individual importance placed on each motif, it simply means that, in cases in which the neutral model is not rejected, there is no need to search for additional reasons or narratives to explain the diversity or distribution of motifs. Under conditions of neutrality, the choices made are individual and idiosyncratic, with no forces pushing them in particular directions. In cases where the neutral model is rejected, we can examine the motif frequencies for clues about the external process which may have led to the observed non-neutral level of diversity. We have attempted to do this at the end of each section of our neutral model results (chapter 4), but as we have seen, causality is extremely difficult to ascribe. In many cases there is no perceptible difference between what can be observed in samples that reject the neutral model and those that do not. This, of course, is why we do tests rather than judging things by eye. As will be seen in our discussion, our results in their present state can be applied quite readily to existing problems in research into figure-painted pottery.

Before we do so, however, there are some aspects of figure-painted pottery which must be examined more closely. We first need to examine the relationship between shapes and motifs. This will tell us the degree to which individual motifs were specialised to each shape. We will then examine the variability and turnover rate of motifs, as this will help us understand our neutral model results more clearly. We will also conduct another test of

12 This is an important point when it comes to behaviours which are done "for" something, but whose specific form at any given time is almost certainly neutral. Following fashions in clothing, for example, could reasonably be described as a form of costly signalling (Miller 2000), but one need only look at the difference between fashion in the 1970s and fashion now to see that the specific form this behaviour takes is arbitrary.

13 Some may say that it is these specific individual choices, not the population outcomes, which are truly of interest. Such individual motivations are not preserved in the archaeological record, and indeed as interviews with artists today illustrate even if they were they would have little external applicability.

the neutral model, using the top y technique from Bentley et. al. (2007). Finally, we will examine the changing frequencies of techniques, and examine the relationship between technique, shape and motif, in order to explore the much discussed transition from black-figure to red-figure in greater detail.

It is necessary for us to explore these correlations because no previous study has demonstrated the actual relationship between the key variables of date, motif, shape and technique. Much previous research contains implicit assumptions about the relationship which exists between these variables, but no study, including that of Webster (1972), has used a sample of figure-painted pottery as large as the one used in this study, and therefore the links remain unproven. Until we have an understanding of the relationships between these key variables, we cannot begin to interpret our results.

### 5.1.2 Top 10

Before we begin to look for associations between variables, we will briefly consider the individual trajectories of popular motifs in each shape. Figures 5.1 to 5.24 show the top ten highest frequency motifs for each shape and technique, across all testable date categories. In each figure, we show the proportion each of the ten highest frequency motifs represents out of all motifs in that shape, technique and date category. These figures can help us to recognise periods in which some motifs appear to gain exceptional popularity relative to other motifs included in our study. However, it is important to keep in mind that in each date category there are hundreds of lower frequency motifs which make up proportions of 1% or less. As we have seen in our power law results, the majority of motifs in all samples occupy this “long tail”, similar to the long tail of book titles sold in very small numbers by online retailer Amazon (Anderson 2006). Motifs from this low frequency, long tail pool can become popular, as can be seen in many of the figures (such as satyrs in figure 5.1), but the vast majority remain at low frequency.

In addition to illustrating the relative frequencies of common motifs, the figures also clearly show the transition between different “classes” of motifs, as discussed in the introduction to this section. We can see this in the cups sample in figures 5.1 to 5.3. In figure 5.3, we see that in 600 – 550 and 575 – 525 , warriors, horsemen and sirens are high frequency motifs. In 550 - 500 and 525 – 475, the proportion made up by these motifs is reduced, while “Dionysiac” motifs (satyrs, maenads and Dionysos) are at a high frequency. Warriors are also common, but do not have as great a proportion of the total as they did in the earliest sample. From 500 – 450 onwards we see another change, with athletes becoming more than twice as frequent as satyrs and maenads. In the last two samples, 425 – 375 and 400 -300, we see in the red-figure cups sample (figure 5.2) that Eros is also a high frequency motif. Thus, the change in the “tone” of popular motifs reported by Shapiro (1990) is supported by evidence in the highest frequency motifs. As discussed in the previous section, however, this does not mean that we must accept the political and psychological explanations given by Shapiro (1990) or Neer (2002) as being the “reason” for this change. The observed patterns could also be the outcome of the process of innovating and copying itself. In fact, if we look at the results of our neutral model tests, we see that in periods in which the above transition took place (575 – 525, 525 – 475 and 450 – 400), the neutral model is not rejected in cups. Only in the periods between changes in the types of motifs found on cups do we see greater than expected diversity. This suggests that a process of random copying could have produced the changes observed, but between changes painters produced more variation than expected under conditions of neutrality.

When assessing “psychological” theories against the data itself, we are at something of a disadvantage. While a psychological explanation can pick and choose motifs to specifically support a given position, regardless of their frequency, we can only assess each sample as a whole. We do not yet have the ability to test the changing frequencies of individual motifs against the neutral model.[14] Therefore, motifs such as athletes in the red-figure cup sample (figure 5.2), which appear to be exceptionally popular, cannot be said to be under selection even when the neutral model is rejected, as our results reject the neutral model based on all sampled motifs, not just those that are popular or of interest to researchers. In red-figure cups for example, the neutral model was rejected in 475 – 425, 425 – 375 and 400 – 300 samples (table 4.12.7), as the sample was more diverse than expected. This result indicates that there are more mid to high frequency motifs than expected for the given sample size and mutation rate. In this case this includes athletes as well as satyrs, maenads and Eros. In the remaining samples, including 450 – 400 when athletes were found on 32% of sampled red-figure cups, the neutral model was not rejected. As we have discussed previously, a key prediction of the neutral model is that by chance alone some motifs will be many times more popular than other motifs, as athletes

14 However, such tests are planned for future studies, as a model which does exactly this is being developed by Adam Powell, UCL Department of Biology.

are in this sample. Strong evidence would be required to show that their popularity was based on other factors external to the process of copying itself.

There are, however, several motifs which appear to exceed the popularity that would be expected under conditions of neutrality. In black-figure skyphoi and black-figure cups (figures 5.1 and 5.4), we see that sirens, sphinxes, warriors and horsemen have a very high frequency in 600-550. This is due to the sample sizes in this date category being relatively small, and the number of motifs observed also being small. This leads each motif which is present to make up a high proportion of the total. Similarly, the high frequency of Athena in black-figure amphorae in 500 – 450 (figure 5.16) and the high frequency of warriors in black-figure lekythoi in 475 – 425 (figure 5.13) is also due to the sample size shrinking and the number of motifs observed being greatly reduced. This is caused by the transition to red-figure and the consequent reduction in sample size of all shapes in black-figure. While it is reasonable to find these motifs at high frequency on these shapes (as per Webster 1972), the combined red-figure and black-figure samples (figures 5.13 and 5.18) provide a more accurate assessment of the relative frequency of these motifs overall.

In red-figure, some motifs have a very high frequency in the last date category 400 – 300. This is at least partly due to the sample size and the number of motifs in use being reduced in this final sample, following the changes in diversity in all shapes observed in 425 – 375.[15] This can have the effect of increasing the relative proportion of some motifs. In 400 – 300 in red-figure we find athletes at high frequency on oinochoe (figure 5.8), cups (figure 5.2) and skyphoi (figure 5.5). We also see that Eros has a very high frequency on hydria (figure 5.20) in all samples from 475 – 425 onwards. Eros is also very frequent on red-figure lekythoi (figure 5.14), as is Nike in 500 to 450 and 475 to 425.

The high frequency of Nike on lekythoi in 475 – 425 is clear even in the combined black-figure and red-figure sample ( figure 5.15). All lekythoi samples from 500-450 onwards reject the neutral model and are more diverse than expected.[16] Therefore, it is likely that this peak in the frequency of the Nike motif is the result of a process external to copying itself, and requires further examination.[17] The high frequency of Eros on hydria (figure

15 Recall that all shapes rejected the neutral model during this period, but that the overall sample did not. This will be discussed in full in the conclusion.

16 We would expect the presence of one very high frequency motif to indicate conformity. However, our tests indicate more diversity than expected in this sample. Because we assess each sample as a whole, and not individual motifs, some results may appear counter-intuitive.

17 Which we will address in our conclusion, after other aspects of our samples have been explored.

5.21) should also be explored further. Other motifs, including athletes on cups, oinochoe and skyphoi, do not appear to be exceptionally frequent, once the small sizes of the terminal samples are accounted for.

Given that our results are based on all sampled motifs in each date category, we will not dwell further on the individual motif trajectories shown in figures 5.1 to 5.24. In each shape and technique, the list of the ten most frequent motifs is unique, but the motifs included in these lists are very similar across all shapes. In the next section we will examine the relationship between shape and motif more closely.

## 5.2 Motif specialisation

### 5.2.1 Motif proportions

We will now examine the relationship between shape and motif. According to Webster (1972), we should expect to find that the shape of a pot determines the motifs found on it. At this stage we will be assessing correlations only, but statistical tests of what follows will form part of future research.

In the previous section, we looked at motifs by date in order to see change over time. In this section we will treat each motif and technique combination as a single sample, with all of the date categories added together.[18] We calculated the sum of appearances of all sampled motifs, then divided this total by the number of motifs which appear on each shape. This produced the proportions shown in table 5.36 below.

| | Pyxis | Cups | Lekythoi | Plates | Ritual | Skyphos | Amphorae | Hydria | Oinochoe | Krater |
|---|---|---|---|---|---|---|---|---|---|---|
| black-figure | 1.2% | 9.8% | 32.4% | 0.6% | 0.2% | 4.9% | 31.0% | 6.2% | 11.3% | 2.5% |
| red-figure | 3.0% | 18.3% | 17.2% | 0.7% | 1.0% | 3.6% | 18.2% | 8.4% | 6.6% | 23.0% |
| black and red-figure | 1.9% | 13.2% | 26.3% | 0.6% | 0.5% | 4.4% | 25.9% | 7.1% | 9.4% | 10.7% |

Table 5.4. Proportion of motifs found on each shape.

These proportions are partly determined by sample size (more pots means more motifs), but also are affected by the number of sampled motifs which appear on each individual pot. Red-figure kraters may have been used for more complex, multi-figured scenes,

18 We have the ability to address this question by date, but we will not do so in this project as the quantity of results would be rather overwhelming (10 shapes x 3 technique combinations x 3 to 9 date categories), and would not provide a better answer to the simple question at hand, which is whether some motifs are specifically associated with some shapes.

which would increase their overall proportion of the total, while slender lekythoi may have been used for scenes involving only one or two figures. These considerations do not affect any of our previous calculations, which thus far have been completely internal, with counts in one shape having nothing to do with the results of another.

These motif proportions give us an expected proportion of each motif. For example, if in black-figure 4.9% of all motifs are found on skyphoi, then we would expect to find 4.9% of all depictions of Theseus in black-figure on skyphoi. To determine whether this is the case, we divide the proportion of each motif by the expected proportion. A result of 1 (100%) means that the motif being considered appears at the expected frequency, and we conclude that there is no special association between that motif and that shape in that technique. A result of less than 1 (less than 100%) indicates that the motif appears less often than it should. A result of 2 (200%) or more is considered a strong association between that motif and that shape, as it shows that the motif appeared more than twice as often as expected.

Rather than examine on the 10 highest frequency motifs, as in the previous section, we here look at the 50 highest frequency motifs. A list of 50 motifs will keep the results manageable, but will also contain enough variation to show whether motifs are associated with shapes. The 50 highest frequency motifs make up the vast majority of motifs in each technique by quantity. In black-figure, the 50 highest frequency motifs account for 92.6% of all motifs by overall quantity, while in red-figure they represent 84.8% of the total, and in the combined sample 88.0%. While in the previous section we produced a different list for each shape and technique sample, we here use the same list within each technique.

### 5.2.2 Top 50

The proportions of each of the 50 highest frequency motifs are shown in figures 5.25 to 5.54. In each figure, the proportion shown on the y axis represents the result of a comparison between the proportion of each motif on the x axis and the proportion for that shape, shown in table 5.4 above. A result of 1 indicates that the motif appears in the same proportion as the shape itself in that technique. A result of 2 or greater for a motif indicates that there is a strong association between that shape and that motif. As above, 2 (which represents a proportion of 200% of expectations) is an arbitrary measure. We could have used 150%, or 300%. But given that the variation in most motifs is between

50% and 150%, as shown in the figures, a threshold of 200% serves best to answer the question of whether some motifs or groups of motifs have an affinity with some shapes.

The results of these calculations are summarised in tables 5.5 to 5.7. The tables show all motifs in the "top 50" which are found more often than expected on each shape. In each technique, we can see that overall, most motifs are found in proportion to the shape sample itself. However, shapes with small sample sizes, including pyxis, plates and ritual shapes, tend to have more motifs associated with them than the shapes with larger sample sizes. This is because the smaller the sample size, the more each individual appearance of a motif makes up of the total. This can lead a small actual frequency to represent a large proportion, such as the motif "wedded pair" which is found 2597.7% more often than expected on ritual shapes (figure 5.37).

Even allowing for the small sample sizes of some shapes, the analysis shows that there is an affinity between some shapes and some motifs. Generally these affinities are expressed only in motifs found below the level of the 10 highest frequency motifs. This means that the high frequency motifs are common on all shapes, but the slightly less frequent motifs are more unevenly distributed. It is also noteworthy that some motifs which are associated with a shape in black-figure also show an affinity with that shape in red-figure. These include Hephaistos on plates and kraters, Aphrodite on hydria and pyxis, and Paris on pyxis and plates. This shows that in these cases, there was a strong affinity between the shape and the motif.

The frequencies of the motifs used on hydria (figures 5.46 to 5.48) are notably different from those of other shapes. Despite having a large overall sample size (n=1740), we find many motifs at a higher proportion than would be expected for their sample size (11 out of 50 motifs in black-figure and 10 out of 50 motifs in both red-figure and black-figure and red-figure combined). We also see that many motifs, such as satyrs, maenads and athletes, which are common on other shapes are much less frequent on hydria. This suggests that motifs on hydria formed a different set of possibilities from those that were common on other shapes. The neutral model results for hydria show that 5 out of 8 of the testable samples did not reject the neutral model, but the remaining 3 were less diverse than expected. A result of less than expected diversity indicates conformity. This would tend to concentrate frequencies in the motifs which were present, leading to the over-abundance of many motifs as seen in figures 5.46 to 5.48.

| BLACK FIGURE | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pyxis | Siren | Helen | Sphinx | Aphrodite | Zeus | Paris | Hera | Poseidon | Pegasoi | | | | |
| | 1127.60% | 813.40% | 582.00% | 485.60% | 391.00% | 353.60% | 334.30% | 322.10% | 250.30% | | | | |
| Cups | Horsemen | Centaur | Siren | Huntsmen | Pegasoi | Nike | Nessos | | | | | | |
| | 334.70% | 334.30% | 278.30% | 255.10% | 235.50% | 231.60% | 204.10% | | | | | | |
| Lekythoi | none | | | | | | | | | | | | |
| Plates | Nessos | Siren | Sphinx | Huntsmen | Helen | Centaur | Hephaistos | Aphrodite | Leto | Paris | Hera | Thetis | Peleus |
| | 1167.60% | 477.60% | 397.30% | 364.90% | 350.30% | 302.00% | 287.10% | 261.40% | 257.60% | 253.80% | 239.90% | 230.40% | 223.10% |
| Ritual | Wedded Pair | Aphrodite | Paris | Hera | Siren | Minotaur | Hermes | Theseus | Sphinx | | | | |
| | 2597.70% | 1964.50% | 1907.50% | 1803.00% | 598.30% | 522.30% | 427.30% | 394.10% | 229.70% | | | | |
| Skyphos | Sphinx | Huntsmen | | | | | | | | | | | |
| | 536.30% | 213.40% | | | | | | | | | | | |
| Amphorae | Helen | | | | | | | | | | | | |
| | 200.00% | | | | | | | | | | | | |
| Hydria | Wedded Pair | Nereus | Charioteer | Triton | Kerberos | Iolaos | Kyknos | Zeus | Aphrodite | Hermes | Hera | | |
| | 509.90% | 418.60% | 347.80% | 296.60% | 269.10% | 266.60% | 252.30% | 248.40% | 241.00% | 222.30% | 221.20% | | |
| Oinochoe | Odysseus | Amazon | | | | | | | | | | | |
| | 250.70% | 216.30% | | | | | | | | | | | |
| Kraters | Hephaistos | Charioteer | Kyknos | Odysseus | Wedded Pair | | | | | | | | |
| | 525.50% | 308.20% | 250.40% | 226.80% | 210.90% | | | | | | | | |

Table 5.5. Black figure: motifs in the top 50 whose proportion is 200% or more of the shape.

| RED FIGURE | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Pyxis | Erotes | Nereid | Paris | Peleus | Thetis | Griffin | Eros | Muse | Aphrodite | |
| | 1215.5% | 455.0% | 322.6% | 322.6% | 313.6% | 279.4% | 259.3% | 252.8% | 244.6% | |
| Cups | Diskoboloi | Hoplitodromoi | Acontist | Athlete | Trainer | Archer | | | | |
| | 346.3% | 346.3% | 340.5% | 273.6% | 233.9% | 205.0% | | | | |
| Lekythoi | Charon | Siren | Sphinx | Nike | Artemis | Iris | | | | |
| | 582.8% | 454.4% | 420.9% | 321.8% | 219.8% | 208.9% | | | | |
| Plates | Nereid | Archer | Minotaur | Hephaistos | Erotes | Helen | Poseidon | Athena | Kephalos | Paris |
| | 844.6% | 353.7% | 307.5% | 282.9% | 249.7% | 248.2% | 228.2% | 227.4% | 224.6% | 224.6% |
| Ritual | Erotes | Nike | Eros | Leto | | | | | | |
| | 787.0% | 412.6% | 360.2% | 217.2% | | | | | | |
| Skyphos | Iris | Athlete | | | | | | | | |
| | 262.3% | 227.8% | | | | | | | | |
| Amphorae | Griffin | Zeus | | | | | | | | |
| | 260.0% | 225.5% | | | | | | | | |
| Hydria | Peleus | Persephone | Paris | Muse | Triptolemos | Leto | Helen | Aphrodite | Thetis | Demeter |
| | 339.9% | 318.6% | 302.1% | 301.8% | 297.4% | 297.4% | 271.3% | 271.0% | 264.4% | 258.0% |
| Oinochoe | Athlete | | | | | | | | | |
| | 284.3% | | | | | | | | | |
| Kraters | Ariadne | Hephaistos | | | | | | | | |
| | 258.5% | 217.6% | | | | | | | | |

Table 5.6. Red figure: motifs in the top 50 whose proportion is 200% or more of the shape.

| BLACK FIGURE AND RED FIGURE | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Pyxis | Erotes | Siren | Eros | Griffin | Helen | Aphrodite | Paris | Sphinx | Muse | Hera | Nereid |
| | 1871.6% | 658.5% | 399.4% | 393.7% | 390.0% | 359.0% | 355.6% | 298.3% | 289.8% | 264.1% | 229.0% |
| Cups | Diskoboloi | Acontist | Athlete | Trainer | Horsemen | Centaur | Huntsmen | | | | |
| | 409.9% | 364.8% | 291.4% | 251.8% | 246.6% | 226.7% | 205.2% | | | | |
| Lekythoi | Goddess | | | | | | | | | | |
| | 208.6% | | | | | | | | | | |
| Plates | Siren | Sphinx | Nereid | Helen | Hephaistos | Erotes | Paris | Poseidon | | | |
| | 384.6% | 334.6% | 312.1% | 299.0% | 288.2% | 282.3% | 242.3% | 213.3% | | | |
| Ritual | Erotes | Nike | Eros | Paris | Hera | Aphrodite | Muse | King | | | |
| | 1617.8% | 743.0% | 729.3% | 297.7% | 248.7% | 238.6% | 218.3% | 206.8% | | | |
| Skyphos | Sphinx | | | | | | | | | | |
| | 488.5% | | | | | | | | | | |
| Amphorae | none | | | | | | | | | | |
| Hydria | Muse | Nereus | Aphrodite | Demeter | Paris | Iolaos | Eros | Triton | Hera | Leto | |
| | 329.7% | 328.6% | 291.8% | 282.6% | 256.9% | 234.5% | 231.1% | 229.2% | 214.6% | 214.5% | |
| Oinochoe | none | | | | | | | | | | |
| Kraters | Hephaistos | | | | | | | | | | |
| | 278.6% | | | | | | | | | | |

Table 5.7. Black figure and red figure: motifs in the top 50 whose proportion is 200% or more of the shape.

While we do not intend to interpret the symbolic meaning of motifs, it is undeniable that some of the motifs found at high frequency within a single shape are thematically related. The pyxis shapes have an affinity with motifs to do with love (Aphrodite, Paris and Helen). Cups and skyphoi have an affinity with athletic and hunting motifs (trainers, athletes, archers and centaurs). Lekythoi in black-figure are not particularly associated with any motif, but in red-figure we find motifs which would be appropriate for use in the context of a funeral or dedication, such as Charon, Nike, sirens and sphinxes. This suggests that the specialisation of lekythoi as a shape for use in these contexts did not emerge until 500 – 450 and after. This is an interesting result, as, if we return to our neutral model results (table 4.12.7), we see that from 500 to 450 onwards all lekythoi samples reject the neutral model and are more diverse than expected. Plates show an affinity with many motifs, but as described above this is a side effect of their very small sample size (n=354 for black-figure and red-figure combined). Ritual shapes have a similar issue, but the motifs we do find at high frequency are among those we might expect to find used on a vase intended as a dedication or gift (wedded pair, Aphrodite, Paris, Hera[19]). Individually, oinochoe show an affinity with Odysseus and Amazons in black-figure and athletes in red-figure, but when the two techniques are combined, the proportion of these is in line with the proportion of oinochoe against the sample overall. Kraters show a very strong affinity with Hephaistos, probably as part of the “Return of Hephaistos” scene in which Dionysos gets the god drunk in order to bring him back to Olympus, an appropriate scene for a vessel intended for the mixing of wine.

However, these motifs which are found in excess of the expected proportion are the exception, not the rule. This is especially clear if we look beyond the 50 most frequent motifs. We calculated the proportions of all 665 motifs sampled and compared these with the expected proportion for each  shape in black-figure and red-figure combined. The results are summarised in table 5.8 below.

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19 Because the aim of our study is to assess each shape sample overall, rather than each individual motif, we did not examine the relationships between motifs, though it would have been possible for us to do so. However, many are apparent even from these results. For example, on pyxis we find Peleus and Thetis both at high frequency. The “Judgement of Paris” also seems to have been popular on pyxis in black-figure and on hydria in red-figure, as we find Paris, Helen, Hera and Aphrodite all at very high frequencies. Athena is missing from this list as this figure is found more frequently on other shapes, leading the expected proportion to be high enough to counteract the effects of the small pyxis sample size. Such associations could be explored further in future studies.

| black-figure and red-figure | Pyxis | Cups | Lekythoi | Plates | Ritual | Skyphos | Amphorae | Hydria | Oinochoe | Krater |
|---|---|---|---|---|---|---|---|---|---|---|
| Total motifs | 141 | 233 | 282 | 73 | 39 | 143 | 327 | 235 | 200 | 273 |
| Total number of motifs with >200% proportion and which appeared 10 or more times | 41 | 16 | 10 | 22 | 16 | 12 | 14 | 48 | 4 | 23 |
| Proportion of above | 29.08% | 6.87% | 3.55% | 30.14% | 41.03% | 8.39% | 4.28% | 20.43% | 2.00% | 8.42% |

Table 5.8. Summary results for all 665 motifs, black-figure and red-figure combined.

As can be seen from these results, the number of motifs whose proportion is 200% or more than expected and which appeared 10 or more times is less than 10% in cups, lekythoi, skyphoi, amphorae, kraters and oinochoe. In pyxis, plates, ritual shapes and hydria, however, the number of over represented motifs is much larger. We know that our results for pyxis, plates and ritual shapes are affected by small sample size, and that in these samples each motif appears to have a greater proportion than it should because the shape proportion itself is small. In hydria, however, it does appear that the set of motifs that were copied to high frequency is very different to that of other shapes.

### 5.2.3 Unique motifs

We will now consider whether some motifs were unique to some shapes. The first line of table 5.9, below, shows the number of motifs which are found on one shape only. The second line shows the number of motifs which appear on one shape only and appear once only. As we can see, almost all the motifs which are unique to each shape also appear only one time. This shows that not all innovations were copied, and that many innovations died out within a single shape before they had a chance to be copied to other shapes. A system of random copying and innovation will tend to produce a large number of very low frequency motifs as well as a few exceptionally high frequency motifs.

| black-figure and red-figure | Pyxis | Cups | Lekythoi | Plates | Ritual | Skyphos | Amphorae | Hydria | Oinochoe | Krater |
|---|---|---|---|---|---|---|---|---|---|---|
| Total number of motifs which appear on this shape only | 24 | 46 | 46 | 8 | 4 | 18 | 77 | 39 | 22 | 51 |
| • Of these, total number of motifs which appear once only | 22 | 45 | 40 | 8 | 4 | 18 | 68 | 35 | 21 | 49 |
| • Of these, number of motifs which appear five or more times | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Table 5.9. Unique motifs.

Only two motifs appeared on one shape only and appeared 5 or more times. These are Kerkyon, who appears exactly 5 times on cups and nowhere else, and Charon, who appears 63 times on lekythoi. Kerkyon was a wrestler who would force travellers to a match and kill them. He himself was killed by Theseus (Henle 1973: 82), and is depicted as part of the "deeds of Theseus". Heroic and athletic motifs were popular on cups (figures 5.1 to 5.3), though Theseus himself is found in proportion to the sample size of cups (figures 5.28 to 5.30). Charon was the ferryman of the dead and is therefore an appropriate motif to find on lekythoi. Given their themes, these motifs therefore appear to represent the most extreme end of the affinity between shapes and motifs.

We conclude from the above discussion that with few exceptions, all motifs were available to be used on all shapes. However, within each shape, a few motifs became very popular, and are found at frequencies in excess of the expected proportion based on the sample size of each shape, according to the arbitrary measure of 200% used above. While random copying can account for these frequencies, it could also be the case that we are detecting a bias which reinforced the copying of some types of motifs on some shapes. We have established from our neutral model results that in a majority of cases, the frequency distribution and diversity of motifs in each shape sample are indistinguishable from random copying. It therefore appears that shape does influence motif, but the process of random copying itself in most cases determines the distribution of those motifs.[20]

20 We should also keep in mind that the above discussion is based on the compression of all dates together into one sample, while our neutral model results are calculated from each date category individually. In future research we intend to analyse the proportions of motifs within each date category and compare these with our neutral model results.

## 5.3 Variation

### 5.3.1 Through time variation

Having examined the popularity of motifs over time in section 5.1 and the association between motifs and shapes in section 5.2, we will now look at the variance of motifs. Variance here represents the change in proportion of the motif against the total in each time step. While we could easily perform this analysis within each shape and technique sample, for clarity we will use the counts for the black-figure and red-figure overall sample, with all shapes and techniques combined.

We begin with the same calculation of proportion used in section 5.1. We compare the total number of appearances of each motif with the sum of all motifs which appeared in that time step. This gives us the motif proportion. The ten motifs with the greatest proportion were used in the discussion in section 5.1. Then, rather than calibrating this against the shape proportion, as in section 5.2, we simply subtract the proportion of each motif in the previous time step from the proportion for that motif in the current time step. The result is the change in proportion for that motif between the present time step and the previous time step. A result of 0 indicates no change, as the motif makes up the same proportion of all the motifs in the present time step as it did in the previous time step. A positive result means that the motif has increased in proportion, and has become more popular. A negative result means that the motif has decreased in proportion, and has become less popular.

### 5.3.2 Herakles vs. Theseus

The resulting measure tells us how variable each motif is in relation to other motifs, and crucially separates change from quantity. To illustrate the difference between this measure and others we have used, we make a comparison between Herakles and Theseus. In figure 5.56, we see a comparison between the actual numbers of the two motifs in the database. It is readily apparent that Herakles is many times more popular than Theseus, until 500 to 450, when Herakles' frequency drops below that of Theseus, after which the two motifs are nearly equal in popularity. From this, we infer that Theseus does not become popular, but rather that Herakles fails to remain popular, which is a different process entirely. We can see this more clearly in figure 5.57, which shows the same motifs, but as proportions of all motifs observed for each period. In this figure, we see that Theseus does in fact become more popular, going from under 1% of the total in 525 to 475 to slightly over 2% in 475 to 425. Meanwhile, Herakles, frequency decreases from a peak of over 8% of the total in 550 to 500 to just above 1% in 475 to 425. However, from this low point, depictions of Herakles increase gradually, until by 425 to 375, the Herakles motif is more than twice as popular as Theseus.

These variations are made even clearer in figure 5.58, which shows only the change in proportion of each motif. Here we see that despite having data for Herakles in 600 to 550 and Theseus for 575 to 525, there is nothing on the chart for these periods, as these are the starting points for the motifs and there are no data before this from which to plot change. At first glance we would assume that for Herakles, the period from 575 to 525 to 500 to 450 is a steady decline, but figure 5.57 shows that the motif's frequency actually increased for the first of these periods, and kept decreasing into 475 to 425. In fact, this is what figure 5.57 shows. The proportion change in 575 to 525 is just under 4%. This is the initial increase shown in figure 5.57, from slightly over 3% in 600 to 550 to 7% in 575 to 525. Then, from 575 to 525 to 550 to 500, we see an increase of only slightly more than 1%, which, indeed is what figure 5.58 shows. It looks like a decrease, but in fact it is simply a smaller increase than in the previous period. It is only in 525 to 475, when the proportion for Herakles crosses to below 0% that we see a real decline, and this continues until 450 to 400, when the proportion for Herakles finally stabilises. The rise from -4% in 500 to 450 to -3% in 475 to 425 is still a decrease in frequency, but it is a smaller decrease, and shows us that the Herakles motif is now not declining in popularity quite as fast. We then see a small increase in frequency, followed by a stabilisation with a slight decrease in frequency. The frequency of the Theseus motif, on the other hand, simply oscillates between 1% and -1%. It neither increases nor decreases in frequency by a notable amount. From this we can see that proportion change can show us a great deal about the overall frequency variation of a motif. We must keep in mind, however, that all negative results represent a decrease in frequency, and all positive results represent increases in frequency. Moving from a decrease with a high amplitude to a decrease with a low amplitude means the frequency of the motif is decreasing less. Moving from a high positive value to a lower positive value means the frequency of the motif is increasing less. Zero, as above, represents no change.

### 5.3.3 Top 10

Figure 5.58 shows the variance for all motifs which are found 10 or more times across all shapes and techniques. Table 5.10, below, shows the 40 most variable motifs. Note that, as above, the samples do not begin until one date period after the motif's first appearance, as there is no way to assess change without a prior sample.

The results clearly show that for almost all motifs, the overall variance is well within the range of +5% and -5%. This means that the proportion of the total made up by these motifs did not change by a significant amount once they were introduced. If we contrast these results with our earlier results for drift and mutation within each shape, we see that there was little variance in the frequencies of motifs.

However, there are some obvious exceptions. We can see these more clearly if we look only at the ten most variable motifs, sorted by total absolute variance, as shown in table 5.11, which is the sum of all unsigned variance differences. The resulting list, shown in figure 5.59, shows a scale-distorting drop in the proportion of motifs made up by sirens and sphinxes between 600 to 550 and 575 to 525. Between these two periods, the numbers of both motifs actually increased, from 86 to 156 sphinxes and 128 to 150 sirens. However, many other motifs also appeared in vast numbers in 575 to 525, so that the proportion shared by sirens and sphinxes decreased sharply. Warriors and satyrs increased in proportion, as did Dionysos, Athena, athletes and maenads, though their prior proportion change is not shown, as it is the starting frequency. Nike remained almost the same. After this, between 575 to 525 and 550 to 500, the frequency of siren and sphinx motifs continues to decrease, but at a much lower rate, while the frequency of warrior motifs declines sharply. Athena continues to increase, but less so than in the previous time step, while athletes and Nike remain nearly the same. Satyrs, maenads and Dionysos increase during this period. To see the changes in the remaining date samples, we move on to figure 5.60, which shows the most variable motifs from 550 onwards only. This has the effect of removing sirens, which become very stable after their initial fluctuations, and are therefore no longer of interest for the present discussion. They are replaced in figure 5.60 by Herakles, whom, as we have seen, has quite a more variable history.

However, the changing fortunes of Herakles are sedate in comparison with those of Nike and Eros. The proportional frequency of Nike is unchanged between 550 to 500 and 525 to 475, but rises sharply between 525 to 475, then rises again between 500 to 450 and 475 to 425. This peak also corresponds with the peak in Nike motifs observed on red-figure lekythoi, as discussed in the previous sections. With the exception of warriors in 575 to 525, this is the single biggest increase in frequency seen by any motif, in any period. However, this is followed by the biggest decrease in frequency observed in any motif (aside from sirens and sphinxes as discussed above). After this depictions of Nike stabilise in 425 to 375, then decrease again. Eros, who enters the system slightly later, also follows a different course to the other motifs, but here we see continuous growth until 425 to 375, after which there is a large reduction in the proportion of pots depicting Eros. It is also interesting that the increase in depictions of Eros in 450 to 400 is contemporary with the decrease in depictions of Nike.

Other motifs, within the ten most variable, have less turbulent histories. The frequency of sphinxes, Dionysos, satyrs and maenads decreases between 525 to 475 and 500 to 450, then increases until  400 to 300. Though Dionysos is certainly popular throughout, his greatest increase in popularity is made early, in 550 to 500. Herakles, as discussed above, and Athena decrease in proportion in all periods after 550 to 500, until 425 to 375, when they increase slightly, followed by stabilisation. After a peak in popularity in 575 to 525, warriors decline in every subsequent period except the last, in which they make a modest gain. Athletes increase or are stable in every period except 425 to 375, which, as we have seen, is a period in which many motifs are not copied in many shapes and overall sample size decreases. It is noteworthy, however, that within the ten most variable motifs this only affects athletes and warriors. Other motifs are either stable or make gains in proportion in 425 to 375. As we have seen in the individual shape samples (and in table 5.12 below), the middle of the distribution is most affected by this drop, which would have the effect of increasing the proportional share of the top motifs.

| BF and RF All Shapes | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 | Overall N |
|---|---|---|---|---|---|---|---|---|---|---|
| Satyr | -2.96% | 3.92% | 4.27% | 2.15% | -2.18% | -0.21% | 0.86% | 0.05% | 1.06% | 3552 |
| Warrior | 3.43% | 8.26% | -3.25% | -1.95% | -3.18% | -0.93% | -0.88% | -4.49% | 0.47% | 3394 |
| Maenad | * | 1.82% | 4.88% | 3.45% | -2.29% | 0.55% | -1.61% | 1.01% | 2.40% | 3122 |
| Dionysos | * | 2.97% | 5.70% | 2.62% | -5.58% | -2.36% | -0.99% | 2.25% | 2.11% | 2937 |
| Herakles | * | 3.68% | 1.28% | -0.42% | -4.06% | -2.68% | 0.18% | 0.91% | -0.40% | 2010 |
| Athena | * | 4.25% | 2.27% | -1.62% | -0.78% | -2.26% | -0.56% | 1.09% | -0.79% | 1706 |
| Athlete | * | 2.23% | -0.55% | 0.28% | 2.51% | 1.03% | 2.19% | -2.13% | 4.79% | 1673 |
| Nike | * | 0.13% | -0.21% | 0.16% | 4.46% | 8.18% | -7.53% | 0.91% | -2.44% | 1142 |
| Hermes | * | 1.35% | 1.17% | -1.70% | -0.45% | -0.24% | 0.27% | 1.98% | -2.04% | 1077 |
| Eros | * | * | * | 0.08% | 0.82% | 2.32% | 7.04% | 5.38% | -2.70% | 868 |
| Horsemen | 2.32% | 1.03% | -3.77% | -1.91% | -0.86% | -0.49% | 0.50% | -0.80% | 0.20% | 861 |
| Apollo | -4.07% | 0.82% | 1.61% | -0.18% | -0.24% | -0.01% | 1.28% | -1.95% | -0.46% | 830 |
| Sphinx | 6.50% | -16.74% | -5.83% | 0.59% | -1.00% | -0.17% | 1.50% | 2.20% | -4.03% | 725 |
| Goddess | * | 0.41% | 0.69% | 1.79% | -1.40% | -0.55% | -1.06% | 0.57% | -0.30% | 709 |
| Siren | -7.92% | -28.68% | -5.36% | -1.20% | 0.09% | 0.48% | -0.68% | -0.06% | -0.01% | 508 |
| Archer | * | * | 1.58% | -0.76% | 0.40% | -1.44% | -0.05% | -0.11% | 0.07% | 422 |
| Theseus | * | * | -0.68% | -0.03% | 1.01% | 0.25% | -0.24% | -1.28% | -0.11% | 383 |
| Amazon | * | * | 0.41% | 0.77% | -0.52% | -0.37% | 0.84% | -0.17% | 1.09% | 382 |
| Artemis | * | -0.05% | 0.47% | -0.21% | 0.36% | 0.87% | -0.36% | -0.65% | -0.76% | 351 |
| Ariadne | * | * | 0.44% | -0.06% | -0.62% | -0.26% | 0.19% | 0.40% | 1.08% | 346 |
| Achilles | -2.68% | -0.43% | -0.13% | -0.07% | -0.26% | -0.38% | -0.22% | * | * | 294 |
| Giant | * | * | 0.37% | 0.36% | -0.45% | -0.65% | -0.04% | 0.06% | -0.21% | 291 |
| Zeus | * | 0.63% | -0.80% | -0.51% | 1.68% | -0.36% | -1.16% | 0.29% | -0.31% | 262 |
| Trainer | * | * | 0.03% | -0.07% | 1.52% | -0.87% | -0.05% | 0.21% | -1.12% | 253 |
| Aphrodite | * | * | -0.29% | -0.15% | 0.05% | 0.27% | 1.36% | 2.33% | -1.19% | 248 |
| Iolaos | * | * | 0.46% | -0.83% | -0.23% | -0.39% | 0.07% | 0.15% | -0.02% | 245 |
| Poseidon | * | 0.13% | -0.08% | -0.21% | 0.80% | -0.23% | -0.83% | 0.35% | 0.31% | 227 |
| Griffin | * | * | -0.29% | 0.03% | 0.11% | -0.15% | 0.21% | 0.63% | 5.87% | 215 |
| Acontist | * | * | * | 0.40% | 0.60% | -0.23% | 0.29% | -0.94% | * | 214 |
| Thetis | * | 0.13% | -0.01% | 0.54% | -0.03% | -0.42% | -0.35% | -0.02% | -0.01% | 208 |
| Nereid | * | * | 0.06% | 0.57% | 0.00% | -0.47% | -0.01% | * | * | 207 |
| Peleus | * | * | -0.03% | 0.63% | -0.28% | -0.35% | -0.29% | * | * | 201 |
| Ajax | * | * | 0.35% | -0.16% | -0.47% | -0.04% | -0.18% | * | * | 190 |
| Minotaur | * | * | -0.66% | -0.22% | 0.14% | -0.33% | -0.07% | * | * | 174 |
| Erotes | * | * | * | * | * | -0.10% | 2.43% | -0.75% | 1.89% | 170 |
| Eos | * | -0.23% | 0.00% | 0.10% | 0.76% | 1.37% | -1.58% | * | * | 163 |
| Hera | * | 0.36% | -0.26% | -0.16% | 0.51% | 0.08% | -0.30% | 0.35% | -0.64% | 158 |
| Diskoboloi | * | -0.19% | 0.06% | 0.46% | 0.37% | -0.70% | 0.33% | -0.48% | -0.09% | 148 |
| Paris | * | 0.04% | -0.27% | -0.12% | 0.06% | 0.09% | 0.48% | 0.52% | -0.83% | 133 |
| Hephaistos | * | * | -0.09% | -0.07% | 0.06% | 0.24% | -0.33% | 0.38% | -0.47% | 114 |

Table 5.10. Turnover rate for the 40 motifs observed the greatest number of times in the database, across all shapes and techniques.

| BF and RF All Shapes | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 | Total change |
|---|---|---|---|---|---|---|---|---|---|---|
| Siren | -7.92% | -28.68% | -5.36% | -1.20% | 0.09% | 0.48% | -0.68% | -0.06% | -0.01% | 44.49% |
| Sphinx | 6.50% | -16.74% | -5.83% | 0.59% | -1.00% | -0.17% | 1.50% | 2.20% | -4.03% | 38.56% |
| Warrior | 3.43% | 8.26% | -3.25% | -1.95% | -3.18% | -0.93% | -0.88% | -4.49% | 0.47% | 26.83% |
| Dionysos | * | 2.97% | 5.70% | 2.62% | -5.58% | -2.36% | -0.99% | 2.25% | 2.11% | 24.57% |
| Nike | * | 0.13% | -0.21% | 0.16% | 4.46% | 8.18% | -7.53% | 0.91% | -2.44% | 24.02% |
| Eros | * | * | * | 0.08% | 0.82% | 2.32% | 7.04% | 5.38% | -2.70% | 18.34% |
| Maenad | * | 1.82% | 4.88% | 3.45% | -2.29% | 0.55% | -1.61% | 1.01% | 2.40% | 18.02% |
| Satyr | -2.96% | 3.92% | 4.27% | 2.15% | -2.18% | -0.21% | 0.86% | 0.05% | 1.06% | 17.66% |
| Athlete | * | 2.23% | -0.55% | 0.28% | 2.51% | 1.03% | 2.19% | -2.13% | 4.79% | 15.71% |
| Athena | * | 4.25% | 2.27% | -1.62% | -0.78% | -2.26% | -0.56% | 1.09% | -0.79% | 13.62% |
| Herakles | * | 3.68% | 1.28% | -0.42% | -4.06% | -2.68% | 0.18% | 0.91% | -0.40% | 13.60% |
| Horsemen | 2.32% | 1.03% | -3.77% | -1.91% | -0.86% | -0.49% | 0.50% | -0.80% | 0.20% | 11.88% |
| Apollo | -4.07% | 0.82% | 1.61% | -0.18% | -0.24% | -0.01% | 1.28% | -1.95% | -0.46% | 10.63% |
| Hermes | * | 1.35% | 1.17% | -1.70% | -0.45% | -0.24% | 0.27% | 1.98% | -2.04% | 9.20% |
| Griffin | * | * | -0.29% | 0.03% | 0.11% | -0.15% | 0.21% | 0.63% | 5.87% | 7.28% |
| Goddess | * | 0.41% | 0.69% | 1.79% | -1.40% | -0.55% | -1.06% | 0.57% | -0.30% | 6.78% |
| Zeus | * | 0.63% | -0.80% | -0.51% | 1.68% | -0.36% | -1.16% | 0.29% | -0.31% | 5.74% |
| Aphrodite | * | * | -0.29% | -0.15% | 0.05% | 0.27% | 1.36% | 2.33% | -1.19% | 5.64% |
| Erotes | * | * | * | * | * | -0.10% | 2.43% | -0.75% | 1.89% | 5.16% |
| Charon | * | * | * | * | * | 0.21% | 2.08% | -2.22% | * | 4.51% |
| Archer | * | * | 1.58% | -0.76% | 0.40% | -1.44% | -0.05% | -0.11% | 0.07% | 4.41% |
| Amazon | * | * | 0.41% | 0.77% | -0.52% | -0.37% | 0.84% | -0.17% | 1.09% | 4.17% |
| Achilles | -2.68% | -0.43% | -0.13% | -0.07% | -0.26% | -0.38% | -0.22% | * | * | 4.16% |
| Eos | * | -0.23% | 0.00% | 0.10% | 0.76% | 1.37% | -1.58% | * | * | 4.04% |
| Trainer | * | * | 0.03% | -0.07% | 1.52% | -0.87% | -0.05% | 0.21% | -1.12% | 3.86% |
| Artemis | * | -0.05% | 0.47% | -0.21% | 0.36% | 0.87% | -0.36% | -0.65% | -0.76% | 3.72% |
| Theseus | * | * | -0.68% | -0.03% | 1.01% | 0.25% | -0.24% | -1.28% | -0.11% | 3.62% |
| Ariadne | * | * | 0.44% | -0.06% | -0.62% | -0.26% | 0.19% | 0.40% | 1.08% | 3.03% |
| Poseidon | * | 0.13% | -0.08% | -0.21% | 0.80% | -0.23% | -0.83% | 0.35% | 0.31% | 2.94% |
| Diskoboloi | * | -0.19% | 0.06% | 0.46% | 0.37% | -0.70% | 0.33% | -0.48% | -0.09% | 2.67% |
| Hera | * | 0.36% | -0.26% | -0.16% | 0.51% | 0.08% | -0.30% | 0.35% | -0.64% | 2.67% |
| King | * | * | -0.01% | -0.06% | 0.40% | 0.91% | -0.82% | -0.27% | -0.17% | 2.64% |
| Tithonos | * | * | * | * | 0.43% | 0.94% | -1.24% | * | * | 2.61% |
| Acontist | * | * | * | 0.40% | 0.60% | -0.23% | 0.29% | -0.94% | * | 2.45% |
| Paris | * | 0.04% | -0.27% | -0.12% | 0.06% | 0.09% | 0.48% | 0.52% | -0.83% | 2.41% |
| Muse | * | * | * | -0.02% | -0.06% | 0.85% | 0.32% | -0.97% | -0.17% | 2.39% |
| Demeter | * | * | * | 0.03% | 0.44% | 0.41% | -0.83% | 0.52% | 0.11% | 2.33% |
| Giant | * | * | 0.37% | 0.36% | -0.45% | -0.65% | -0.04% | 0.06% | -0.21% | 2.15% |
| Iolaos | * | * | 0.46% | -0.83% | -0.23% | -0.39% | 0.07% | 0.15% | -0.02% | 2.15% |
| Helen | * | * | -0.31% | -0.24% | 0.19% | 0.04% | 0.58% | -0.27% | -0.24% | 1.87% |

Table 5.11. Turnover rate for the 40 motifs with the greatest absolute total variance, across all shapes and techniques.

Table 5.12 below summarises the top winners and losers for each period.

| | Largest increases | Largest decreases |
|---|---|---|
| 600 - 550 | Sphinx (6.5%) | Siren (-7.92%) |
| 575 - 525 | Warrior (8.26%) | Siren (-28.68%) |
| 550 - 500 | Dionysos (5.70%) | Sphinx (-5.83%) |
| 525 - 475 | Maenad (3.45%) | Warrior (-1.95%) |
| 500 - 450 | Nike (4.46%) | Dionysos (-5.58%) |
| 475 - 425 | Nike (8.18%) | Herakles (-2.68%) |
| 450 - 400 | Eros (7.04%) | Nike (-7.53%) |
| 425 - 375 | Eros (5.38%) | Warrior (-4.49%) |
| 400 - 300 | Griffin (5.87%) | Sphinx (-4.03%) |

Table 5.12. Largest increases and decreases of the overall proportion for each period.

As is so often the case, today's winners are tomorrow's losers, and many motifs appear in both columns. However, of all the transitions we have discussed, it is the rise and fall of Nike which is most in need of explanation. It is a situation analogous to Herzog *et. al.* (2004)'s dog breeds analysis, in which the registration of dalmatians peaked after the release of Disney's *101 Dalmatians*, and then declined sharply. We have seen that this peak is rooted in the sudden appearance of a huge number of red-figure lekythoi bearing this motif, but why that may have happened requires further discussion. It appears a similar process was happening to Eros after its peak in 425 to 375, but the samples (and figure-painted pottery as a whole) end before this can take place.

Also of interest in table 5.12 is the result that the period 525 to 475 shows the least distance between the largest increase and the largest decrease. We can also see this in figure 5.58. In fact this small range of variance was the norm for nearly all motifs. What is unusual about 525 to 475 is that the outliers which so strikingly appear in other periods are absent. We can conclude from this that the period between 550 to 500 and 525 to 475 was one of stability in motif production, and that the periods on either side were more variable. This also correlates with a shift in "tone" in popular motifs, as discussed in the previous section. In the next, and final, section of motif results we will discuss the turnover rate of motifs, and what this can tell us about the dynamics of the motif system as a whole.

## 5.4 Turnover rate

### 5.4.1 Top y lists

In the previous section we looked at changes in proportion in each motif. In this section, we will examine changes in the turnover rate of motifs. As Bentley *et. al.* (2007: 152) describe, "the random copying model predicts a regular turnover in particularly popular variants". In this paper Bentley et. al. used a model to predict the turnover rate in cultural data, given the parameters mutation, sample size and size of the top y list. In this section we use Bentley *et. al.*'s model to test the turnover rate of motifs in our sample, as described in chapter 2.

As in the previous section, here we use only the data from the black-figure and red-figure combined sample for all shapes. While we certainly could repeat this procedure for each of the 33 different combinations of shapes and techniques, it is not possible to do so in the scope of this thesis.

To begin, we created lists of top 5, 10, 20, 30, 40 and 50 motifs. Two examples of these are shown in tables 5.13 and 5.14 below. These are the motifs which appear the most times in each time step. It should be noted that for this analysis we do not examine the changing position of a motif within a list, but instead whether a motif is present in a list of a given size defined by the top y. As can be seen from these tables, turnover rate is determined by the appearance of new motifs within a given top y list. In table 5.13, for example, we see that the top 5 list for 575 to 525 is the same as the previous time step, giving us a turnover rate of 0, while in 550 to 500, we see that three new motifs have entered the top 5 list, giving us a turnover rate in the top 5 of 3. Table 5.14 shows that as the top y list grows larger, the turnover rate also tends to increase.

| Top 5 motifs by date category | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 600 to 550 | 575 to 525 | 550 to 500 | 525 to 475 | 500 to 450 | 475 to 425 | 450 to 400 | 425 to 375 | 400 to 300 |
| Siren | Warrior | Warrior | Dionysos | Satyr | Nike | Eros | Eros | Eros |
| Sphinx | Horsemen | Satyr | Satyr | Maenad | Satyr | Satyr | Satyr | Athlete |
| Warrior | Sphinx | Dionysos | Maenad | Warrior | Maenad | Athlete | Maenad | Satyr |
| Horsemen | Herakles | Herakles | Warrior | Dionysos | Warrior | Maenad | Athlete | Maenad |
| Herakles | Siren | Maenad | Herakles | Athlete | Athlete | Warrior | Nike | Dionysos |

Table 5.13. Turnover of motifs in the top 5, for all shapes, black-figure and red-figure. New entries are shown shaded

| Top 10 motifs by date category | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 600 to 550 | 575 to 525 | 550 to 500 | 525 to 475 | 500 to 450 | 475 to 425 | 450 to 400 | 425 to 375 | 400 to 300 |
| Siren | Warrior | Warrior | Dionysos | Satyr | Nike | Eros | Eros | Eros |
| Sphinx | Horsemen | Satyr | Satyr | Maenad | Satyr | Satyr | Satyr | Athlete |
| Warrior | Sphinx | Dionysos | Maenad | Warrior | Maenad | Athlete | Maenad | Satyr |
| Horsemen | Herakles | Herakles | Warrior | Dionysos | Warrior | Maenad | Athlete | Maenad |
| Herakles | Siren | Maenad | Herakles | Athlete | Athlete | Warrior | Nike | Dionysos |
| Hermes | Satyr | Athena | Athena | Nike | Dionysos | Nike | Dionysos | Griffin |
| Achilles | Athena | Hermes | Goddess | Athena | Eros | Apollo | Sphinx | Nike |
| Satyr | Dionysos | Horsemen | Athlete | Herakles | Athena | Dionysos | Hermes | Erotes |
| Athlete | Athlete | Athlete | Hermes | Hermes | Apollo | Erotes | Aphrodite | Aphrodite |
| Memnon | Hermes | Apollo | Apollo | Apollo | Eos | Charon | Athena | Amazon |

Table 5.14. Turnover of motifs in the top 10, for all shapes, black-figure and red-figure.

| Top y | 575 to 525 | 550 to 500 | 525 to 475 | 500 to 450 | 475 to 425 | 450 to 400 | 425 to 375 | 400 to 300 |
|---|---|---|---|---|---|---|---|---|
| 5 | 0 | 3 | 0 | 1 | 1 | 1 | 1 | 1 |
| 10 | 2 | 2 | 1 | 1 | 2 | 2 | 4 | 3 |
| 20 | 6 | 4 | 4 | 8 | 4 | 6 | 4 | 4 |
| 30 | 10 | 8 | 5 | 4 | 8 | 8 | 10 | 7 |
| 40 | 16 | 9 | 9 | 10 | 11 | 13 | 13 | 9 |
| 50 | 23 | 11 | 6 | 14 | 9 | 16 | 18 | 16 |

Table 5.15. Turnover rate of motifs for given top y lists, black-figure and red-figure, all shapes. Turnover is defined as the number of new motifs within a given top y list from period to period. This does not mean the motifs were not present in the previous time step, only that they were not copied at a level sufficient to put them in the given top y list.

The results of all top y list counts are shown in table 5.15 above, and in figure 5.61. Note that we do not analyse 600 to 550, as this is the starting period and we have no previous period with which to create a top y turnover rate. As we can see, there is a strongly linear trend (r-squared = 99.6) in the distribution of top y turnover rates, as expected under the neutral model. The list for each period is also a distribution, and to assess these, we must now turn to our model.

As in our main results, in order to evaluate whether or not the neutral model is rejected in a given sample, we establish a model population with the same parameters and compare the results with those of our real world data. As described on page 154 of Bentley *et. al.* (2007), the model begins with N individuals (which, in our case can be imagined as pots), each with a unique variant. At each time step, each individual randomly copies a variant from the previous time step, or innovates a new variant with a probability equal to the parameter mutation set at the beginning of the run. This continues for every time step until the model is stopped, at which point top y lists are created from the distribution of variants in the last time step. We then compare these with those of our real world data.

### 5.4.3 Results

The results of each top y comparison are shown in figures 5.62 to 5.69. In each figure we see the distribution of turnover rates produced by the model compared with the distribution of turnover rates found in our data. We compared each of these using a linear regression analysis, the results of which are shown in table 5.16 below.

| | | | | | Regression analysis | | |
|---|---|---|---|---|---|---|---|
| Period | N | mutation fraction | Model R-squared | Data R-squared | t | p | result |
| 575 to 525 | 2315 | 0.045 | 0.999 | 0.984 | 2.864 | 0.021 | significant |
| 550 to 500 | 6622 | 0.010 | 0.999 | 0.940 | 0.660 | 0.528 | not significant |
| 525 to 475 | 9232 | 0.010 | 0.999 | 0.775 | -0.639 | 0.541 | not significant |
| 500 to 450 | 5698 | 0.013 | 0.998 | 0.818 | 0.873 | 0.408 | not significant |
| 475 to 425 | 6734 | 0.018 | 0.999 | 0.869 | -1.119 | 0.296 | not significant |
| 450 to 400 | 4010 | 0.027 | 0.999 | 0.990 | 1.521 | 0.167 | not significant |
| 425 to 375 | 1165 | 0.004 | 0.975 | 0.962 | 3.286 | 0.110 | not significant |
| 400 to 300 | 2561 | 0.006 | 0.999 | 0.923 | 3.423 | 0.009 | significant |

Table 5.16. Results of comparison with model for given top y lists, black-figure and red-figure, all shapes.

The results show that in 575 to 525 and in 400 to 300, there is a significant difference between the top y distribution found in the data and the top y distribution found in our model. In these cases we reject the neutral model. In the remaining periods the test shows no significant difference between the regression formed by the model and that formed by the data from the respective top y lists, so in these cases we do not reject the neutral model.

### 5.4.4 Conclusion

We compare these results with our master results table for our theta test in table 5.17 below.

| | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|
| R SQUARED | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| THETA | 0 | < | < | 0 | 0 | 0 | 0 | < |
| TOP Y | X | 0 | 0 | 0 | 0 | 0 | 0 | X |

Table 5.17. Theta results vs. r-squared vs. top y results. 0 = neutral model not rejected. X = neutral model rejected < = neutral model rejected, sample less diverse than expected.

As can be seen in table 5.17, we have tested the distribution of motifs in our sample of pots using three different techniques. All three tests agree that the four periods between 500 to 450 and 425 to 375 do not reject the neutral model. In the remaining periods, we see less diversity than expected in 400 to 300 as well as a rejection of the neutral model on the basis of the top y lists. As we have seen, this period followed a collapse in sample size, which reduced diversity. The number of motifs turning over in this period is less than in the previous period (table 5.51 above), and this was enough to reject the neutral model in this case. However, we do not see a similar result in 550 to 500 and 525 to 475, which are also less diverse than expected. In 575 to 525 we see neutral levels of diversity, but we find that the motif turnover rate is non-neutral. We saw in section 5.3 (especially figure 5.58) that this period was also one of transition, with a large number of new motifs entering the system. While the overall diversity was neutral, we find it entirely reasonable that the turnover rate in this period was not.

While these top y results have their shortcomings, their consistency with previous results is encouraging, and leads us to both support the methods used in Bentley *et. al.* (2007) and to conclude that the random copying model accounts for much of the variation observed in the distribution of figure-painted pottery motifs.

# Chapter 6

# Techniques

## From black to red

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6.1 Techniques

Our final set of results concerns techniques. Technique refers to the variation in the relation between figure and ground achieved through differences in slips applied, their manner of application, and the techniques for their modification once applied. So far, we have discussed only the two major techniques, black-figure and red-figure, but there are several sub-techniques which we will now examine in detail.

| technique | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 | total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Added Colour | 0 | 0 | 0 | 2 | 7 | 1 | 4 | 9 | 42 | 102 | 167 |
| Coral Red | 0 | 0 | 1 | 3 | 7 | 4 | 0 | 0 | 0 | 0 | 15 |
| Semi Outline and Outline | 0 | 1 | 13 | 15 | 8 | 9 | 20 | 21 | 41 | 99 | 227 |
| Silhouette | 1 | 1 | 2 | 55 | 121 | 62 | 23 | 23 | 2 | 1 | 291 |
| Six | 0 | 0 | 0 | 7 | 85 | 15 | 3 | 1 | 1 | 1 | 113 |
| White ground | 0 | 1 | 2 | 149 | 918 | 792 | 859 | 835 | 11 | 2 | 3569 |
| black-figure | 61 | 621 | 2308 | 6523 | 7811 | 1530 | 101 | 15 | 31 | 60 | 19061 |
| red-figure | 0 | 1 | 7 | 99 | 1421 | 4168 | 6633 | 3995 | 1134 | 2501 | 19959 |

Table 6.1. Techniques and sub-techniques by date.

Table 6.1 and figure 6.1 show the distribution of all techniques by date. All pots in the database are classified as either black-figure or red-figure. Every sub-technique, including white ground, is a sub-technique of either of these. We will therefore deal with black-figure and red-figure separately from sub-techniques, in order to prevent the samples from overlapping. Figure 6.2 shows the distribution of sub-techniques only and figure 6.3 shows the distribution of minor sub-techniques. We will often examine the five minor sub-techniques independently of white ground due to the difference in magnitude of their frequencies.

From table 6.1 and figures 1 to 3, we can see that sub-techniques make up a very small proportion of the overall sample of pots. Of the six sub-techniques, only white ground was produced in large numbers. The other five, added colour, coral red, outline, silhouette and six technique, appear at very low frequencies. There were two distinct periods in which sub-techniques were popular: 525 to 475 and 400 to 300. Silhouette and six technique were popular in the first peak, while added colour and outline were popular in the second peak. Coral red also has its peak in the first period, but with a maximum sample size of seven never catches on with Athenian potters.  Outline is the first technique to appear more than ten times, in 575 to 525, but by the following period, white ground has completely eclipsed it and all other sub techniques.

Figures 1 and 2 clearly show that, once developed, white ground makes up a small but consistent proportion of total pot production. Sample sizes of white ground pots peak in 525 to 475 at 918 pots, then level off until collapsing, along with all other pot production, in 425 to 375. Unlike red-figure and even black-figure to a small extent, once white ground falls out of use it is not revived in 400 to 300.  Other sub-techniques, outline and added colour, are far more popular than white ground in this final period.

| | BLACK-FIGURE | RED-FIGURE |
|---|---|---|
| Added Colour | 11 | 185 |
| Coral Red | 5 | 11 |
| Outline | 56 | 206 |
| Silhouette | 220 | 79 |
| Six | 122 | 3 |
| White ground | 1539 | 2248 |

Table 6.2. Distribution of sub-techniques between black-figure and red-figure

As described above, all sub-techniques are a sub-type of either black-figure or red-figure. Table 6.2  shows how these sub-types are distributed. Added colour and outline are primarily sub-techniques of red-figure, while silhouette and six technique are sub-types of black-figure. Given when each sub-technique peaked, these are not surprising results, but it may indicated a difference in the way each main technique diversified. Black-figure sub-techniques appeared when black-figure was at its peak, in 525 to 475, while the red-figure sub-techniques first appear in large numbers when red-figure was at its lowest, in 425 to 375. White ground, on the other hand, was produced in larger numbers as a sub-technique of red-figure, but the transition between the two main techniques was surprisingly even, as shown in table 6.3 and figure 6.4. In 500 to 450, when black-figure was declining and red-figure was ascending in popularity, the number of white ground pots appearing as  a sub-set of each main technique was nearly equal. This shows us that production of white ground pots, was relatively high, constant and steady, and was not influenced by whether the pots were black-figure white ground or red-figure white ground.

| | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 |
|---|---|---|---|---|---|---|---|---|---|---|
| BF White ground | 0 | 1 | 1 | 147 | 900 | 379 | 66 | 6 | 1 | 0 |
| RF White ground | 0 | 0 | 1 | 2 | 18 | 413 | 793 | 829 | 10 | 2 |
| White ground overall | 0 | 1 | 2 | 149 | 918 | 792 | 859 | 835 | 11 | 2 |

Table 6.3. White ground as a sub-technique of black-figure and red-figure.

If we return to table 6.1 above, we can see that white ground and red-figure emerged around the same time. In fact, in 550 to 500, black-figure white ground (n=149) was more popular than red-figure (n=99). However, red-figure went on to replace black-figure, while white ground was used only in special circumstances.

Figure 6.5 shows a log log plot of the probabilities and frequencies of all techniques in all dates, including black-figure and red-figure, with a power law regression line. The r-squared value for this regression is very high (0.9844), and though we have seen that high r-squared plots are easy to produce, the result itself remains: techniques and sub-techniques are distributed according to a power law. If we look only at 525 to 475 (figure 6.6), we see that the distribution of technique frequencies conforms even more closely to a power law, with an r-squared value of 0.9978. (While all sub-techniques are included in this sample, their number is not enough to change the bin in which black-figure appears, or its consequent probability). This shows that during the same period in which red-figure first appeared in large numbers, the distribution of frequencies of techniques is in accordance with a prediction of the neutral model, which is that variants will be distributed in a power law (Bentley *et. al.* 2004).

It may therefore be that the popularity of red-figure itself is a product of random copying and innovation. Its distribution shows neither an overly steep rise nor the appearance of active constraint, both of which are indicative of a non-neutral variant, as illustrated by the frequency distribution of white ground. Every pot that was made in red-figure instead of black-figure increased the likelihood that another red-figure pot would be made, while decreasing the likelihood that another black-figure pot would be made. In 550 to 500, all techniques appear at least twice, yet only red-figure and white ground go on to be copied in large numbers. White ground, as we have seen, was constrained, but there was nothing to stop the spread of red-figure. Red-figure may simply be a sub-technique that got lucky.

## 6.2 Technique and shape

Having reached this conclusion, we will now go on to examine on which shapes this random copying was occurring. We will see from these results whether some shapes were used for experiments in technique more often than others.

Table 6.4 below shows the distribution of techniques on each shape. As we can see, white ground is entirely concentrated in lekythoi, which is expected, given that nearly all white ground pots are lekythoi. Other techniques are also more common on lekythoi than other shapes, with the exception of coral red, which is almost exclusively used on cups. Figure 6.7 shows the distribution of sub-techniques across shapes. The value for white ground lekythoi exceeds the scale of the chart by many orders of magnitude. We can see that white ground was also popular on pyxis, amphorae and oinochoe, but that on other shapes it was no more popular than other sub-techniques. Of course, to get a true measure of how popular each technique was on each shape, we must, as before, correct for sample size.

| | Added Colour | Coral Red | Semi Outline and Outline | Silhouette | Six | White ground | black-figure | red-figure |
|---|---|---|---|---|---|---|---|---|
| Pyxis | 8 | 0 | 8 | 11 | 0 | 23 | 289 | 430 |
| Skyphos | 6 | 0 | 8 | 91 | 1 | 59 | 1358 | 981 |
| Cups | 1 | 14 | 29 | 43 | 1 | 45 | 3116 | 4012 |
| Lekythoi | 34 | 0 | 70 | 33 | 95 | 3353 | 6562 | 5773 |
| Plates | 0 | 0 | 0 | 4 | 1 | 4 | 167 | 187 |
| Ritual | 3 | 1 | 4 | 2 | 7 | 4 | 71 | 173 |
| Amphorae | 31 | 0 | 34 | 11 | 11 | 74 | 4254 | 3104 |
| Hydria | 9 | 0 | 7 | 3 | 2 | 16 | 775 | 965 |
| Oinochoe | 61 | 1 | 59 | 12 | 6 | 176 | 1814 | 1444 |
| Krater | 42 | 0 | 42 | 67 | 1 | 8 | 387 | 2845 |

Table 6.4. Distribution of sub-techniques across shapes.

The results are shown in table 6.4 and figure 6.8. Immediately we can see that there is a problem. By including white ground in our sum of techniques, the fraction of other techniques expected in each shape is minuscule. For example, because 80% of all sub-techniques are white ground, each of the other five techniques are expected in each shape at a level of 5.9% or less. Because 10% of cups in this sub-sample use the coral red sub-technique,  and the expected level of coral red is 0.34%, the result is that there are 3078.29% more coral red cups than there should be. Clearly, to proceed with this line of enquiry we need to eliminate white ground from our sample. Before we do so, however, we should note that white ground appears far less than it should on all shapes except for lekythoi, which are only slightly above the level expected. This confirms the methodology, as in this sample, as we have seen, it is white ground lekythoi that set the level of expectation, so they should naturally come out very close to 100%.

| | Added Colour | Coral Red | Semi Outline and Outline | Silhouette | Six | White ground |
|---|---|---|---|---|---|---|
| Pyxis | 376.39% | | 281.21% | 364.33% | | 56.09% |
| Skyphos | 86.73% | | 86.40% | 925.99% | 22.55% | 44.21% |
| Cups | 18.04% | 3078.29% | 390.89% | 546.12% | 28.14% | 42.08% |
| Lekythoi | 22.57% | | 34.72% | 15.42% | 98.40% | 115.39% |
| Plates | | | | 750.74% | 415.91% | 55.28% |
| Ritual | 342.78% | 1392.56% | 341.47% | 160.87% | 1247.73% | 23.69% |
| Amphorae | 462.01% | | 378.59% | 115.41% | 255.75% | 57.17% |
| Hydria | 526.72% | | 306.07% | 123.60% | 182.60% | 48.54% |
| Oinochoe | 453.15% | 90.54% | 327.46% | 62.76% | 69.53% | 67.77% |
| Krater | 629.87% | | 470.59% | 707.34% | 23.40% | 6.22% |

Table 6.5. Proportions of expected totals of sub-techniques across shapes.

Having eliminated white ground from the sample, the revised results are shown in table 6.5 and figure 6.9. The small sample sizes (there are only 874 pots in total) produce very uneven results, as each individual appearance counts for a noteworthy proportion of the total . On pyxides, we see that the three techniques which appear, added colour, outline and silhouette, do so at the level expected. This means that pyxides were neither popular nor unpopular for experiments with techniques. It is not surprising that coral red was not used for pyxides, as it was hardly used for anything Athenian, while the absence of six technique, which was popular early, is an indication that they were part of the second peak in popularity of sub-techniques. Proportionally, silhouette was most often used on skyphoi. Other sub-techniques were very uncommon on this shape. Coral red only appears more than once on cups, which is why their proportion is so much higher than it should be. These cups appeared over four date categories (table 6.1 above), so this was not a single batch, but rather a very uncommon way of making cups that failed to catch on. Outline and silhouette are represented as expected, while six technique and added colour are rare for this shape. In addition to white ground, all other sub-techniques (except of course coral red) were used on lekythoi. Six technique was especially popular on these shapes, as a sub-technique of  black-figure, during the same period that white ground lekythoi were transitioning from black-figure to red-figure (table 6.3 above). No added colour, coral red or outline plates appear in the database, but there are four which use the silhouette technique (and are therefore over-represented) and one which uses the six technique. It is interesting that sub-techniques were so pervasive that they reached even plates, albeit at low frequency. As in cups and oinochoe, each technique is used at least once on ritual shapes. Coral red appears once, but is calculated as over-represented due to the very small sample size of ritual shapes. Six technique is slightly more common, with four pots, and these also appear to be over-represented. The remaining techniques appear slightly less than expected on ritual shapes.

| | Added Colour | Coral Red | Semi Outline and Outline | Silhouette | Six |
|---|---|---|---|---|---|
| Pyxis | 132.80% | | 99.22% | 128.55% | |
| Skyphos | 25.37% | | 25.27% | 270.87% | 6.60% |
| Cups | 5.09% | 869.03% | 110.35% | 154.18% | 7.95% |
| Lekythoi | 65.69% | | 101.04% | 44.88% | 286.31% |
| Plates | | | | 252.42% | 139.84% |
| Ritual | 79.10% | 321.32% | 78.79% | 37.12% | 287.91% |
| Amphorae | 159.71% | | 130.87% | 39.89% | 88.40% |
| Hydria | 192.09% | | 111.62% | 45.07% | 66.59% |
| Oinochoe | 196.69% | 39.30% | 142.14% | 27.24% | 30.18% |
| Krater | 123.85% | | 92.53% | 139.08% | 4.60% |

Table 6.6. Proportions of expected totals of minor sub-techniques (not white ground) across shapes.

All techniques except for coral red appear on amphorae and hydria, and at levels within the range expected (more than 25%/less than 200%). Added colour is the most popular sub-technique for these shapes. Added colour is also popular on oinochoe, while outline appears as expected, and coral red, silhouette and six technique are uncommon but not excessively. Added colour, outline and silhouette are used at expected levels on kraters, while six technique is uncommon for this shape.

To summarise the above, by looking at the technique frequencies in proportion to sample size, we find that added colour was concentrated on hydria and oinochoe, coral red was concentrated on cups, outline was distributed equally across all shapes except skyphoi and plates, silhouette was favoured for skyphoi and six technique, like white ground, was concentrated on lekythoi. However, with the exception of coral red, all techniques are found on all shapes, with the exception of plates and six technique on pyxis. Therefore, it appears that no shape was a testbed for new techniques. Instead it seems that once techniques were developed they were quickly copied to all other shapes. The frequencies in tables 1 and 3 above show that this happened with red-figure, so we would not expect other sub-techniques to be any different. The only difference is that the other sub-techniques failed to be copied as widely or as rapidly. In contrast, white ground was copied in frequencies comparable to other sub-techniques, but found substantial acceptance only on lekythoi.

## 6.3 Techniques and motifs

Given this result, we do not expect to see much association between motifs and techniques. Table 6.7 below shows the 30 most popular motifs in each technique. In techniques without 30 motifs (coral red, silhouette, six technique), all motifs are shown. The results clearly correspond to our earlier results for motif popularity over time. The motifs depicted in each technique are those that were popular when each technique was popular, or, in the case of white ground and coral red, which were popular on the shape for which the technique was primarily used. Clearly technique was not related to subject matter, instead we once again we see that the primary determinant of motif was shape, and then only within the limits of what was popular at the time.

| Added Colour | | Coral Red | | Semi Outline and Outline | | Silhouette | | Six | | White ground | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Eros | 16 | Warrior | 1 | Eros | 17 | Satyr | 20 | Satyr | 6 | Warrior | 80 |
| Aphrodite | 9 | Nike | 1 | Warrior | 9 | Dionysos | 17 | Siren | 3 | Herakles | 57 |
| Satyr | 8 | Athlete | 1 | Aphrodite | 9 | Maenad | 13 | Warrior | 2 | Dionysos | 40 |
| Dionysos | 6 | Theseus | 1 | Satyr | 8 | Warrior | 8 | Maenad | 1 | Satyr | 39 |
| Griffin | 6 | Minotaur | 1 | Griffin | 6 | Horsemen | 5 | Amazon | 1 | Maenad | 38 |
| Nike | 5 | Kerkyon | 1 | Dionysos | 5 | Athlete | 3 | Horsemen | 1 | Athena | 38 |
| Erotes | 5 | Prokrustes | 1 | Erotes | 5 | Griffin | 2 | Herakles | 1 | Nike | 32 |
| Amazon | 4 | Sinis | 1 | Nike | 4 | Ariadne | 2 | Huntsmen | 1 | Hermes | 32 |
| Maenad | 3 | Skiron | 1 | Amazon | 4 | Herakles | 2 | Theseus | 1 | Charon | 26 |
| Athena | 3 | Diskoboloi | 1 | Maenad | 3 | Goddess | 2 | Minotaur | 1 | Apollo | 23 |
| Pan | 3 | | | Pan | 3 | Huntsmen | 2 | Peleus | 1 | Archer | 21 |
| Warrior | 2 | | | Athena | 2 | Sphinx | 2 | Iris | 1 | Goddess | 20 |
| Ariadne | 2 | | | Ariadne | 2 | Nike | 1 | Eos | 1 | Amazon | 15 |
| Hermes | 2 | | | Hermes | 2 | Athena | 1 | Atalanta | 1 | Horsemen | 15 |
| Hera | 2 | | | Hera | 2 | Hermes | 1 | Kerberos | 1 | Athlete | 12 |
| Adonis | 2 | | | Adonis | 2 | Zeus | 1 | Memnon | 1 | Peleus | 11 |
| Peitho | 2 | | | Peitho | 2 | Pegasoi | 1 | | | Sphinx | 10 |
| Horsemen | 1 | | | Horsemen | 1 | Poseidon | 1 | | | Thetis | 9 |
| Goddess | 1 | | | Herakles | 1 | Archer | 1 | | | Achilles | 8 |
| Zeus | 1 | | | Goddess | 1 | Hephaistos | 1 | | | Nereid | 8 |
| Pegasoi | 1 | | | Huntsmen | 1 | Hekate | 1 | | | Artemis | 7 |
| Paris | 1 | | | Theseus | 1 | King | 1 | | | Hypnos | 7 |
| Demeter | 1 | | | Zeus | 1 | | | | | Thanatos | 7 |
| Poseidon | 1 | | | Pegasoi | 1 | | | | | Giant | 7 |
| Erichthonios | 1 | | | Paris | 1 | | | | | Aphrodite | 6 |
| Persephone | 1 | | | Demeter | 1 | | | | | Theseus | 6 |
| Bride | 1 | | | Erichthonios | 1 | | | | | Eros | 5 |
| Ge | 1 | | | Persephone | 1 | | | | | Eidola | 5 |
| Ares | 1 | | | Bride | 1 | | | | | Muse | 5 |
| Bellerophon | 1 | | | Ge | 1 | | | | | Iolaos | 4 |

Table 6.7. Top 30 motifs in each technique across all shapes. Where several motifs appear at the same frequency within a technique, they have been ranked in order of their overall popularity.

# CHAPTER 7

# DISCUSSION

## TRENDY NIKES AND THE RISE OF RED-FIGURE

### 7.1 Introduction

Having presented our results, we must now consider their meaning in the context of the known histories of figure-painted pottery. Our primary goal was to examine the degree to which motif frequencies are determined by random copying. It is a mixed picture, as we have seen, and leads to many further questions, such as why motifs on some shapes in some periods do not match the predictions of the neutral model while others for the same periods do. While we expect previous research to provide context for some of these results, there is a fundamental difference in approach between our results and the literature of figure-painted pottery we must consider first.

Webster (1972: 48) discusses a bell-krater by the Kleophon painter on which figures are depicted performing a dithyramb. There are six named figures in all: Phrynichos, Amphilochos, Theeomedes [*sic*], Chremes, Pleistias and Epinikos. In seeking to explain the scene and why these names appear, Webster quotes Friis-Johansen, who suggests that Pleistias was an ambassador and that Theomedes appears in an Athenian casualty list. He goes on to propose that the painter was attempting to give the scene a sense of contemporary realism by alluding to figures known to the Athenian public. Webster counters that a more likely scenario was that the vase was "specially ordered by Phrynichos or his choregos for the party which celebrated the performance of the dithyramb".

Whichever of the above scenarios are correct, this example is illustrative of much of the scholarship of figure-painted pottery. Each pot is described in great detail and a narrative constructed as to why certain figures appear and with what names, and, for those pots with a provenance, why it ended up where it did. It is as though the figure-painted pottery scholar seeks to look over the shoulder of the painter while he works and understand his intentions. There can be no doubt that the design of the Beazley archive itself was undertaken with this approach in mind, given that it is very good at storing and displaying information about single pots, but an ineffective tool for making comparisons between them. The designers of the Beazley archive cannot be blamed for not serving an approach for which there was no demand. With the notable exception of Osborne, and Webster to an extent, previous research shows little appetite on the part of figure-painted pottery scholars for comparative quantitative approaches. Indeed there is open hostility to such approaches from some authors (e.g. Marconi 2004b: 39), who feel that Beazley's selection of pots are not representative of figure-painted pottery as a whole, though they offer no alternative other than avoidance of numbers entirely. This bias arises from a basic misunderstanding, as all analysis is ultimately rooted in quantitative judgements. Common comparisons from previous research such as before/after, less/more and preferences for and against are all quantitative assessments, and are no more valid if they arise from a connoisseurial impression based on experience than from a statistical analysis. In fact, they are probably less so.

A focus on particular, unique objects and their history is not specific to scholarship about figure-painted pottery, as this is how most of art history is approached. Each piece has a narrative, from inspiration to creation to sale, and these narratives are then linked to form a story of an artist's life, or the story of a movement or historical period in time. The perceived importance of the piece to the story dictates the level of detail employed, with more important works receiving more attention and less important works forming a supporting role. The public-facing aspects of art history, such as museums, galleries and auction houses, rely upon these stories to provide context for the artwork they display. We do not intend to criticise this type of scholarship. It is a perfectly valid approach to deciphering the inner workings of unique objects. Of course every work has a history, and, as in the example above, we are sometimes lucky enough to be able to infer this narrative from clues left behind. Indeed we have relied heavily upon the identifications of figures recorded in the Beazley archive, all of which arose from the individual study of each vase.

However, there are problems with this approach. First, it can lead scholars to make claims about objects based on their accumulated impressions rather than what can be proven through evidence. An example is Boardman's statement that cups were “cherished possessions, like a favourite pipe” (Boardman 2001: 247). It isn't possible for a third party to look at the evidence available and reach this conclusion, and furthermore it is unclear as to the purpose of the statement itself. Does it mean that cups were carried around or does it mean that cups were highly valued by their owners, as we know to be the case from inscriptions? The tendency to stray outside the bounds of what is known (and knowable) and into subjectivity is endemic in the narrative approach.

More importantly, a focus on individual pots tends to focus only on the outstanding and unique, while ignoring or glossing over the everyday and unexceptional works, despite these being more numerous and therefore, by frequency, more representative. This is only natural. Scholarship in art is ultimately based on collections of art, which by definition focus on high quality, exotic and exceptional examples.[21] However, because our analysis seeks to show the workings of the system as a whole, we need to include all works, “unimportant” and otherwise. Our methods compare all figure-painted pots equally by attribute, without being influenced by (or even aware of) the quality of the work. Rather than sifting through all known pots for the best examples from each period, we approach pottery as aliens visiting London might assess music – Tchaikovsky might be “better”, but Madonna is, by frequency, what the population listen to.

This leads us to the final problem with traditional approaches to figure-painted pottery, which is that it is difficult to change the scale of the analysis. It is as if the goal is to produce a 1:1 map of figure-painted pottery, with each new find or interpretation contributing a little more to the resolution. The difference between this approach and our approach can be understood through Hahn and Bentley's 2003 paper, which showed that baby names in the United States occur at frequencies indistinguishable from random copying. If we approached this problem like a traditional figure-painted pottery scholar, we would want to know the derivation of each name and why each person's name was given, for example being named after a relative or currently popular celebrity or athlete. If followed to the end, this would produce a full resolution picture of all name choices. However, the information would be so unwieldy as to be useless. Each individual is choosing names for a reason, but these reasons at the population level are not what is

21 Indeed it is precisely this competition for which some scholars, such as Geoffrey Miller (Miller 2000), believe art exists at all.

interesting about the system. Only when we look at the outcome of all these choices do we see that the process is one of random copying. Similarly, in Herzog *et. al.*'s (2004) work on dog breeds, only when we look at all breeds together do we see that the turnover rate of dalmatian registrations is far outside the norm, which flags it up as important for further investigation. In neither names nor dog breeds is it relevant to know the individual decisions that went into each choice – the real story is in the aggregate outcomes.

In previous applications of the neutral model to pottery (Neiman 1995, Kohler *et. al.* 2004, Shennan and Wilkinson 2001), the source material was far less well known than figure-painted pottery. In our study, a complex narrative already exists, so, in a process similar to the papers which dealt with dog breeds and baby names, we use the neutral model to show large scale patterns which were not previously visible. We discuss these in two parts below. The first part deals with the question of "what's interesting" about motifs on figure-painted pottery. While seemingly trivial, this is a fundamental question about how motifs change over time. Previous research is full of references to motifs which are "suddenly popular" at particular times, but these judgements are often presented without quantitative backup. We will compare some of these with our results and find out whether there is justification for some of the more common statements, such as the rise in popularity of Theseus and Webster's discussion of Boreas. In part two we will examine the transition from black-figure to red-figure, by returning to our results for the period during which this technique arose. Before we do so however, we will briefly outline the results we have generated up to this point.

## 7.2 Results overview

Over the course of this study, we have accumulated a number of results and observations. Before continuing, it will be useful to list these. For each result, we list the data parameters used and a brief description of the main results.

1. Neutral model results

   A. **Neutral model by shape and technique.** *technique x shape x motif x date.* (pages 70 – 143)

      1. In this section we calculated the frequency distribution and diversity of 665 motifs in 11 shape categories and 10 date categories, each in black

figure, red figure and both combined. Using equivalent values of sample size and mutation rate, we used a computer simulation to generate a predicted value for measures of diversity and frequency distribution from each sample. We then compared the model values with values calculated directly from the data in order to test whether the neutral model could be rejected. In cases in which the neutral model was not rejected, we conclude that random copying can explain the observed distribution of motifs in that sample. In cases in which the neutral model was rejected, we were able to describe whether this was in the direction of greater or less than expected diversity. These results give clues to the process which may have led to the creation of a sample which rejects the neutral model.

2. Extended results

   A. Motifs

      1. **Top 10:** *technique x shape x motif x date.* (pages 151 – 154) In this section we compared the 10 motifs with the highest frequency for each shape and technique over time. These results helped to clarify our neutral model results by showing the changes in frequency of popular motifs.

      2. **Top 50 proportion:** *motif x shape x technique.* (pages 155 – 161) In this section we compared the proportion of the 50 highest frequency motifs across all shapes. The correlations showed that while popular motifs are popular on all shapes, there is a relationship between some shapes and some motifs. This is expressed through some groups of motifs being more strongly associated with some shapes rather than others.

      3. **Variability:** *motif x date.* (pages 163 – 169) In this section, we showed that almost all motifs which occurred 10 or more times had a turnover rate of less than +/-5%. The few motifs with greater variance appear to have been subject to fad-like rises and falls in popularity.

      4. **Turnover rate:** *motif x date.* (pages 170 – 173) In this section we showed that the turnover rate for motifs across all shapes and techniques is not neutral in 575 to 525 and 400 to 300. The neutral model cannot be rejected for the 6 intervening time periods. This agrees with our theta results and r-squared results in a majority of time periods. Differences in the outcomes

can be explained as differences in the aspects of the samples measured by each test.

B. Technique

1. **Techniques over time:** *sub-technique x date.* (pages 174 – 177) These results showed that a number of sub-techniques were invented around the same time, but only red figure and white ground became popular.
2. **Technique by shape:** *sub-technique x shape.* (pages 177 – 180) Though each sub-technique was found at least once on almost every shape, these results show that each sub-technique is strongly associated with one or two shapes.
3. **Technique and motif:** *sub-technique x motif.* (page 181) These results show that sub-technique has no relationship with motif. Some sub-techniques are associated with some motifs, such as coral red and Eros, but this is only because coral red was strongly associated with ritual shapes, and ritual shapes are strongly associated with Eros.

It is important to point out that of the above results, only those involving the neutral model and the motif turnover rates have been subjected to statistical tests. We can be sure of these results, in the sense that we have an indication of the probability that they could have occurred by chance. We have not had an opportunity to statistically test our other results, but even statistically significant correlations are still just correlations and can't be assumed to directly reflect causality. For the present, we have suggested lines of causality where we believe the data indicates they exist. Each combination shown above could easily be its own subject for future studies. At this stage rather than focus on any one set of factors we determined it was more important to show in simplest terms the relationship between shape, technique and motif. Many ideas about the influence each exerts on the others have been put forward in previous research, but these ideas are often presented with little or no support, making them impossible for other researchers to evaluate. By revealing the patterns shown above, we have taken a necessary first step in a comprehensive understanding of figure-painted pottery.

## 7.3 Iconography

There are many approaches to figure-painted pottery, but the literature on iconography is of greatest relevance to our results. This research interprets the scenes on each pot and identifies the figures they contain. These can be mythological, as in our study, but have been extended to include almost every aspect of each scene. The range of scenes covered by scholarship in the past 50 years is impressive. Authors have described the depiction of all manner of mythological characters, including Dionysos (Carpenter 1997, Carpenter and Faraone 1993), Zeus (Arafat 1990), Theseus (Shapiro 1991b, Walker 1995), Herakles (Boardman 1998b, Cavalier 1995, Hannah 1995, Pinney and Ridgway 1981, Woodford 1989), Perseus (Oakley 1982, Oakley 1988b, Topper 2007), maenads (Edwards 1960, Hedreen 1994), nereids (Arnold, Colten, and Pletka 1997) and satyrs (Hedreen 1994, Hedreen 2006), to name but a few. Non-mythological studies are also popular, examples of which include sports scenes (Goossens and Thielemans 1996), women (Osborne 1997), ritualised wine consumption in the symposium (Lissarrague 1990) and even toilet training (Lynch and Papadopoulos 2006). Scholars may also explore the different activities taking place on vases, including both mythological and non-mythological scenes in their discussions. Examples include hunting (Barringer 2001), humour (Mitchell 2004), weddings (Smith 2005) and the role of spectators (Stansbury-O'Donnell 2006). Iconography is also often approached as a key to Athenian attitudes about different subjects, including courtship (Shapiro 1981), mourning (Shapiro 1991a), rape (Stewart 1995) and even the perceived safety of travel (Rosivach 2005). Figure-painted pottery can also be used as evidence for studies in other fields. Many comparisons between painting, poetry and theatre have been made (Lowenstam 1992, Lowenstam 1997), but papers have also been published which deal with depictions of swordsmanship (Cook 1989) and the construction of boats, though there is naturally much debate about how realistic the vase paintings were meant to be (Humphreys 1978, Thurneyssen 1979). Vase painting has even touched palaeontology, in a recent piece which suggests a depiction of a monster may actually be a rendering of a fossilised skull (Mayor 2000).

Clearly there is much to choose from in applying our results. We are constrained however, by the methodology employed in most of these studies. If authors discuss the scenes themselves without considering their relative popularity and how this changes over time, then there is no basis upon which to make a comparison. For this reason we rely heavily on Webster (1972) as a benchmark against which to explore and assess our results, as this continues to be the work most closely related in its aims if not methods to the present study. Furthermore, many studies are too specific for use with our current set of results. Issues such as whether Dionysos is depicted with or without a beard (Carpenter 1997, ch. 6), for example, are beyond what can be captured using the online Beazley archive in its present form. Using our local database, we could make a comparison between bearded and non-bearded depictions by searching for “Dionysos NOT beardless” and “Dionysos beardless”, but this would be a subject for a future study. We could also look for characters together, such as Ajax carrying the body of Achilles. The only difficulty would be scenes whose identification relies on a higher-order judgement, such as “ritual sacrifice”, as the elements which make up such a scene may not all be named in the description (though see conclusion for how this can be overcome).

Given these limitations and the structure of our results so far, we will focus only on comparing our results with studies which deal with a single figure. Within each discussion we will look for statements about when each motif was popular and why, and compare these with our results to see if the perceived popularity of each motif is reflected in a noteworthy change in frequency. However, given the difference in scale between our results and the scale at which most studies in iconography are conducted, many motifs will be difficult to compare.

### 7.3.1 Boreas and Pan

Differences in scale are clearly illustrated by returning to Webster (1972) and his discussion of the myth of Boreas on pages 254 to 255. Webster states that Boreas was summoned to damage the Persian fleet in 480 BC before the battle of Artemision and that the first appearance of Boreas on figure-painted pottery comes soon after this. Webster goes on to state that there are “no less than 35 Boreas scenes by early classical painters and 6 by classical painters”. These statements are mostly borne out by our results. Appearances of Boreas are distributed as shown in table 7.1 and figure 1, for all shapes and all techniques.

| Boreas | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 | Sum of all years |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Number | 0 | 0 | 1 | 0 | 0 | 19 | 14 | 2 | 1 | 2 | 39 |
| proportion | 0 | 0 | 0.05% | 0 | 0 | 0.47% | 0.36% | 0.09% | 0.12% | 0.08% | 0.11% |

Table 7.1. Boreas: number of appearances on all shapes and in all techniques.

Our total of 39 is slightly less than the total of 43 given by Webster and our first appearance is in 575 to 525 BC, rather than after 480 BC, but this is only 1 depiction. Otherwise, our results agree with Webster's description of trends in the popularity of Boreas. This case illustrates a key difference between our results and many discussions of particular motifs found in previous research. As shown in our discussion of turnover rate in chapter 5, a rise from 0 depictions to 19 depictions is simply too small to be visible in our analysis. If we rank all the mythological figures by their total number of appearances across all periods, techniques and shapes, then Boreas is 80th, equal with Hektor. In 500 to 450 BC his 19 appearances make up 0.47% of the total motifs observed for that period, which places him 39th for that period. There is only one way in which Boreas is of interest. If we compare all motifs which appeared in 500 to 450 BC but did not appear in the previous time step, 525 to 475 BC, then we see that Boreas gains the biggest share of any new motif for that period (table 7.2 below).

| | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 | Sum of all years |
|---|---|---|---|---|---|---|---|
| Boreas | 0 | 0.47% | 0.36% | 0.09% | 0.12% | 0.08% | 0.11% |
| Oreithyia | 0 | 0.39% | 0.38% | 0.09% | 0.12% | 0.04% | 0.10% |
| Orpheus | 0 | 0.34% | 0.38% | 0.33% | 0.25% | 0 | 0.12% |
| Erotes | 0 | 0.15% | 0.05% | 2.48% | 1.73% | 3.62% | 0.48% |
| Danae | 0 | 0.12% | 0.08% | 0.09% | 0 | 0 | 0.03% |
| Perithoos | 0 | 0.10% | 0.13% | 0.19% | 0.37% | 0 | 0.06% |

Table 7.2. Proportion of all motifs made up by motifs which first appeared in 500 to 450 BC.

| | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 |
|---|---|---|---|---|---|---|---|
| Motif | Herakles | Theseus | Acontist | Prokrustes | Boreas | Eriphyle | Adonis |
| Proportion | 3.33% | 1.47% | 0.26% | 0.08% | 0.47% | 0.18% | 0.19% |

Table 7.3. Highest proportion made up by motifs which did not appear in the previous time step. 425 to 375 BC and 400 to 300 BC are not shown because they contain no new motifs.

Indeed, as table 7.3 shows, when Boreas first appears, his proportion of representations is higher proportion than any new motif since Theseus. However, the proportion made up by Boreas, along with all new entries for the period 500 to 450 BC shown in table 7.2, is dwarfed by the shares of Satyrs, Maenads, Warriors, Dionysos, Athletes and Nike, each of which make up more than 5% of the total. Furthermore, the turnover rate of the usage of Boreas appears very flat. Because Boreas appears and disappears within a few time steps and never appears more than19 times in a single time period, it is effectively invisible to our analysis of turnover rate. The total variance (which we define as the total sum of the change in proportion made up by each motif in each time step) of Boreas is 0.45%. This places him 88$^{th}$ in a ranked list of turnover rates for motifs, between Eileithyia (0.47%) and Polyphemos (0.43%).

From these results, we see that Webster may have been correct when he correlated the story of the summoning of Boreas in 480 BC with an increase in depictions on figure-painted pottery, though neither Webster's assertion nor our observations demonstrate causality. Yet without this prior knowledge, we would not have known to look in the data for an increase at this time, given that Boreas is “below the radar” in all measurable aspects.

Webster makes another connection between the frequency of motifs and the Persian Wars. On page 254, he proposes that appearances of Pan may have increased after 490 as a result of the story of Pan's help to the Athenians in 490 at Marathon (Webster 1972). Table 7.4 below and figure 1 show the distribution of depictions of Pan for all shapes and all techniques.

| Pan | 625 - 575 | 600 - 550 | 575 - 525 | 550 - 500 | 525 - 475 | 500 - 450 | 475 - 425 | 450 - 400 | 425 - 375 | 400 - 300 | Sum of all years |
|---|---|---|---|---|---|---|---|---|---|---|---|
| number | 0 | 0 | 0 | 0 | 3 | 7 | 7 | 5 | 2 | 19 | 43 |
| proportion | 0 | 0 | 0 | 0 | 0.03% | 0.17% | 0.18% | 0.23% | 0.25% | 0.72% | 0.12% |

Table 7.4. Pan: number of appearances on all shapes and in all techniques.

We can see that Pan appeared at very low frequency in 525 to 475 BC but increased in 500 to 450 BC. Both date ranges overlap the battle of Marathon. We are therefore again able to support Webster's correlation (though again, causality has not been demonstrated). However, the frequencies are so low that we simply would not have detected this association without prior knowledge. Furthermore, from the frequencies, we conclude that the greatest interest in Pan occurred not around 490, but at the end of figure-painted pottery in 400 to 300 BC, when depictions of Pan make up 0.72% of all observed motifs. This is still tiny – less than 1%, but it is a very large increase from the previous time steps, none of which are more than 0.25%. If there was a specific event which led to an increase in depictions in 400 to 300 BC, it was far more influential than Pan's involvement in the battle of Marathon.

This raises the question of whether we *should* look for correlations between changes in frequency of attributes on pottery and contemporary events. Arafat and Morgan (1989) specifically warn against the creation of simplistic narratives to explain changes in pottery, and we tend to agree with this view. For example, a scene depicting Athena parting two warriors which appears in the mid 5th century could be seen as a wish for a peaceful solution to the impending Peloponnesian war. But this is a retrospective determination made by those with a complete view of history. For the patrons and potters active at the time, things would have looked very different. In any case, "identification of political and social allusion at such a general level is a highly subjective matter, and must be treated with great care" (Arafat and Morgan 1989: 332). For the purposes of our present study we seek to avoid such interpretation entirely.

If the "meaning" of a motif is an unreliable clue, then we can also consider the relationship between figure-painted pottery and text and sculpture. Even here, however, we should not expect to find a simple correspondence. Our results show that the frequency of depictions of Athena on figure-painted pottery declines in the mid 5th century. Arafat and Morgan suggest this was due to the "revolutionary treatment" of the birth of Athena on the east front of the Parthenon, "a birth of Athena to end all births" (Arafat and Morgan 1989: 334). Rather than increase the frequency of depictions of Athena, Arafat and Morgan suggest a negative relationship, in which

the sculptural work was so revolutionary it could not be copied. However, once again, this correlation is presented without statistical evidence. The decline in depictions of Athena we see in our data could just as easily be due to drift as to the hypothetical negative influence of the Parthenon sculptures.

This does not mean we should stop looking for correlations, only that we should be very cautious in deploying explanations which imply direct correspondence between events and media. This is hard enough to do today. The coincidence between the release of Disney's *101 Dalmatians* and the increase in registrations of dalmatians, as reported by (Herzog *et. al.* 2004), is a compelling but exceptional example. In Attic figure-painted pottery, we will often not have enough information to do this. It is as if we have the register of breeds but not the cinema listings, or vice versa. Sometimes we will be able to piece together clues, as in the relatively clear cut examples of Pan and Boreas above. Most of the time, however, we cannot.[22]

Even in rare cases in which an explanation is forthcoming, we must be mindful that if the overall results for the sample do not reject the neutral model, then the explanation at hand should only be taken as a possible proximate explanation cause within a wider system of random copying. Our neutral model results in table 4.12.7 show that the diversity, distribution and turnover rate of motifs in 500 to 450 BC are statistically indistinguishable from the predictions of the neutral model. Therefore, the suggestion that Pan and Boreas increase in frequency as a result of their involvement in the Persian War is analogous to the personal decisions that go into choosing a name for a baby, to return to our earlier example. There may be compelling proximate reasons for each individual choice, but when all choices are viewed together they are indistinguishable from random copying. This means that there is no force or bias pushing the choices of individual painters in the same direction, as there was in the case of *101 Dalmatians* in Herzog et. al. (2004).

### 7.3.3 Theseus

Pan and Boreas are very low frequency motifs we would not otherwise have noticed. We will now go on to discuss Theseus, a higher frequency motif with a substantial body of previous research. Theseus is often identified as the Athenian national hero (Shapiro 1991b: 136). The meaning of the myth of Theseus and his relationship with Athens has been well documented elsewhere (*e.g.* Walker 1995), and as we have described above, it is not the meaning of myths that is of interest here. We will instead examine the correlation between the rise in his popularity generally in the late sixth century and the frequency of his depictions on pottery as shown in our results.

The overall frequencies of depictions of Theseus on all shapes and in all techniques are shown in table 7.5 below and figure 7.2.

22 To explore the issue of relationships between figure-painted pottery and other media it would be very interesting to compare the dates of all known Athenian political events, sculptures, plays and poems with the motif frequencies we have shown in this study.

| Theseus | 625-575 | 600-550 | 575-525 | 550-500 | 525-475 | 500-450 | 475-425 | 450-400 | 425-375 | 400-300 | Sum of all years |
|---|---|---|---|---|---|---|---|---|---|---|---|
| number | 0 | 0 | 32 | 67 | 81 | 72 | 79 | 38 | 4 | 10 | 383 |
| proportion | 0 | 0 | 1.47% | 0.78% | 0.76% | 1.77% | 2.02% | 1.78% | 0.49% | 0.38% | 1.08% |

Table 7.5. Theseus: number of appearances on all shapes and in all techniques.

As can be seen, Theseus does appears at a relatively high frequency in 575 to 525 BC. He is one of 62 motifs which appear for the first time in 575 to 525 BC, and is the most popular of these. It is this increase to which authors refer when they discuss the sudden rise in the popularity of Theseus (Neer 2002: 154, Webster 1972: 82). When Theseus does first appear, so too does the Minotaur and Ariadne, as shown in figure 7.2. Their association quickly ends, with Theseus becoming more popular in other contexts or on his own, before he too becomes unpopular in 425 to 375 BC, a period in which many motifs are not copied or are copied in small numbers. The biggest increase in depictions of Theseus after his initial appearance comes in 500 to 450 BC (as table 7.5 shows, there are actually fewer depictions, but as a proportion of all motifs the percentage is much higher). This increase can be related to the recovery of the bones of Theseus in 476/5 BC (Walker 1995: 56). The *Theseion*, or temple to Theseus, was built in Athens soon after this, and was decorated with wall paintings depicting three events from the myths of Theseus: invasion of Attica by Amazons, the battle with the Centaurs and the visit to Poseidon's palace under the sea (Walker 1995: 58). The exact nature of these compositions has been the subject of much discussion (Barron 1972, Woodford 1974), but we can see from figure 7.3 that depictions of centaurs and Poseidon both increase in 500 to 450 BC, while proportions of depictions of Amazons drop during this period. It is possible that the wall paintings were a source of inspiration for vase painters, but other factors, including simple random variation, are also likely to have been important. Viewing figures 7.2 and 7.3 together we can see a transition of depictions of Theseus, from Minotaur slayer to hero of Athens. It is tempting but simplistic to also see the steep decline in the popularity of Theseus in 425 to 375 BC and 400 to 300 BC as an outcome of the Peloponnesian war. However, the frequencies of many motifs declined during these periods, and there is no reason to suppose that a political motive lay behind any of these changes. Overall the frequency of Theseus is very low. At his height in 475 to 425 BC he makes up only 2.02% of all motifs. We would have to know in advance that he was of special interest to the Athenians and worth investigating further.

### 7.3.4 Nike

We will now look at two motifs whose popularity is obvious and unambiguous. These are Nike and Eros.

| Nike | 625-575 | 600-550 | 575-525 | 550-500 | 525-475 | 500-450 | 475-425 | 450-400 | 425-375 | 400-300 | Sum of all years |
|---|---|---|---|---|---|---|---|---|---|---|---|
| number | 0 | 2 | 15 | 41 | 69 | 208 | 519 | 123 | 54 | 111 | 1142 |
| proportion | 0 | 0.56% | 0.69% | 0.48% | 0.64% | 5.11% | 13.28% | 5.76% | 6.67% | 4.23% | 3.23% |

Table 7.6. Nike: number of appearances on all shapes and in all techniques.

The number of appearances and proportions of all motifs for Nike are shown in table 7.6 above and in figure 7.4. In figure 7.4 we have also included the proportion of all motifs made up by Theseus for comparison. This figure clearly shows that Nike was many times more popular than Theseus from 500 to 450 BC onwards, as was Eros from 450 to 400 BC onwards. On this scale, the "explosion" of Theseus scenes in the 6th century can barely be perceived.

Nike is the 8th most popular motif overall, as shown in chapter 5. Only the specific characters Dionysos, Herakles, Athena and the non-specific/generic characters of satyrs, warriors, maenads and athletes are more popular. As the personification of victory, Nike resembles the "generic" figure types more closely than the specific characters of gods and heroes. Like them, Nike can appear multiple times in the same scene, a clear indication that she was not always meant to represent a single specific character, but rather an idea.[23]

It is, however, puzzling that in 475 to 425 BC Nike made up 13.28% of all observed motifs in all techniques and across all shapes. In the previous period, 500 to 450 BC, Nike made up 5.11% of all motifs, and in the following period, 450 to 400 BC, Nike makes up 5.76%. All three figures are very high, but it appears that something happened in 475 to 425 BC which more than doubled Nike's popularity, but which was only temporary, as the figure returns to the previous baseline in the following period. The *LIMC* offers no clues to the reason for this peak, which is not mentioned in the entry.

23 Hence in our searches we had to look for "Nik[ae]", which would return results for both "Nike" and "Nikai". See chapter 3 for an explanation of this system.

In chapter 5 we examined the proportional popularity of the top 10 motifs for each shape and technique and saw that Nike was found in the list of top 10 most common motifs on red-figure skyphoi, oinochoe, kraters, lekythoi and amphorae. However, only in red-figure lekythoi do we see the pronounced spike in appearances of Nike. Figures 5.14 and 5.15 in chapter 5 show that Nike appeared on a staggering 33.9% of all red-figure lekythoi in our sample in 475 to 425 BC. In the previous period, 500 to 450 BC, she appeared on 24.2% of all red-figure lekythoi in our sample, and in the following period, 450 to 400 BC, Nike appears on only 8.7% of red-figure lekythoi.

In chapter 4 we showed that there was a very large increase in the sample size of lekythoi in 550 to 500 BC and 525 to 475 BC. This increase can possibly be attributed to the introduction of laws which sought to tone down excessive display through funerary monuments (Osborne 1997: 27), whose function was replaced with figure-painted lekythoi offerings. However, even if this hypothesis were correct, the increase in the sample size of lekythoi does not correlate with the increase in appearances of Nike, so we cannot link the two events.

It is also possible that we are dealing with a mistake on the part of the scholars who supplied the information in the Beazley archive. While many goddesses are virtually indistinguishable from human women, Nike's winged appearance makes her easy to recognise. She can sometimes be confused with Iris (Arafat 1987, Webster 1972: 177). Webster also suggests that the figure identified in the Beazley archive as Nike on loutrophoroi and nuptial lebetes (grouped together as ritual shapes in our study) may in fact be Aurai, as this would make more sense in the context of a wedding scene (Webster1972: 175). They may also be depictions of Eos. Iris appears 81 times in all (0.23% of all observed motifs – about the same as Pan and Boreas combined), while Eos appears 163 times (0.46%). Given the carelessness evident in some parts of the Beazley archive, it is not hard to imagine a scenario in which nearly all winged females are identified as Nike by default.[24] However, the number of depictions of Nike is so great that it would have to be a very large and consistent error. Even if such an error took place, it is unlikely to have been confined to the single date range shown in the results.

It is also unlikely that the spike in popularity is due to a contemporary statue or wall painting. Representations of Nike in sculpture are much more commonly discussed in existing research than representations of her in figure-painted pottery. Webster speculates

24 Such an explanation could also apply to Eros – if it's male and has wings it must be Eros.

that early depictions of Nike, which show the winged figure in isolation, are illustrations of a statue by Archermos (Webster 1972: 152), but the many different forms Nike takes by the middle of the 5$^{th}$ century make it unlikely that they were all copies of a particular work or set of works.

Nike has few myths specifically associated with her. She sometimes appears with Zeus as his charioteer (Arafat 1990: 24), but in group scenes it is often unclear whether she is meant to appear as herself, or rather as the personification of the idea she represents (Webster 1972: 177). As figure 7.5 clearly shows, only athletes and warriors come close to being as popular as Nike, and while their popularity helps explain hers, it remains unclear why they both remain relatively stable while representations of Nike increase by 8.17%.

As Webster states, the figure of Nike "was pleasing and the purchaser could interpret it as he wished" (Webster 1972: 152). Nike could be used to depict a positive outcome for any situation, from combat to weddings, and it was almost certainly her generic, unspecific nature that sustained her popularity as a figure. We rejected the neutral model in every period for red-figure lekythoi, having found that the samples in each date range were consistently more diverse than expected. As described in chapter 5, this shows us that there were more high frequency motifs than expected. These included Eros, warriors, maenads, sphinxes, Hermes, Artemis, Charon, Athena, Aphrodite and Nike herself. With the possible exception of Charon, Nike would be at home in scenes with any of these motifs, and it is this plurality which contributed to her popularity. We are unable to offer a specific explanation for the spike in 475 to 425 BC, but if future studies show this was the result of appearances in scenes with all popular motifs of the period, then no explanation may be required.

### 7.3.5 Eros

The final motif we will consider is Eros, the well known god of love and desire. As we have seen in figure 7.4 and table 7.7 below, the relative popularity of Eros in 425 to 325 BC exceeds even that of Nike in 475 to 425 BC.

| Eros | 625-575 | 600-550 | 575-525 | 550-500 | 525-475 | 500-450 | 475-425 | 450-400 | 425-375 | 400-300 | Sum of all years |
|---|---|---|---|---|---|---|---|---|---|---|---|
| number | 0 | 0 | 0 | 3 | 12 | 38 | 127 | 220 | 127 | 341 | 868 |
| proportion | 0 | 0 | 0 | 0.04% | 0.11% | 0.93% | 3.25% | 10.29% | 15.68% | 12.98% | 2.45% |

Table 7.7. Eros: number of appearances on all shapes and in all techniques.

Before we discuss what might have contributed to the popularity of Eros, we must consider the background of the period in which his highest level of popularity is observed. We have seen throughout this study that during 425 to 375 BC, the sample size of all pots in all techniques and shapes drops sharply, falling to only 1,165 (table 4.11.2, chapter 4). This is a quarter of the sample size in 450 to 400 BC and less than half the sample size in 400 to 300 BC. While the overall sample does not reject the neutral model in 425 to 375 BC, each of 7 individual red-figure shape samples and each of the 7 combined black-figure and red-figure samples do reject the neutral model during this period. As we saw from our power law tests, many of these samples reject the neutral model because motifs with mid-range popularity were not copied, leaving only the very high and very low frequency motifs in circulation. Eros was one of the high frequency motifs and gained in popularity regardless of what was happening in the rest of the pottery market.

The most convincing explanation for the downturn in Attic figure-painted pottery comes from MacDonald's 1981 paper which describes the emigration of potters from Athens in the late 5th century. While pottery was produced in many locations around the Mediterranean throughout the 6th and 5th centuries, it was not until the end of the 5th century that pottery comparable in style and technique to that made in Athens begins to appear. MacDonald argues that this is not due to imitation by local potters, but rather that it represents the movement of the potters and painters themselves out of Athens and into outlying centres of production. These émigrés were then copied by locals. Evidence for this hypothesis comes from similarities in style between works known to be from Athens and works known to be from elsewhere, such as those by the Pisticci painter (Trendall 1974). Red-figure pottery schools were established at Thurii, Taras, Falerii, Syracuse, Olympia and Corinth, while black-figure was produced at Lipari and Smyrna (Macdonald 1981: 164).

It is not surprising that craftsmen involved in the pottery market would choose to leave Athens at this time. Conditions in Athens at the end of the fifth century must have been appalling. In addition to the threat posed by the Peloponnesian war (431 to 404 BC), a plague broke out in 430 BC, caused by overcrowding of the city by those seeking sanctuary (Rhodes 2006: 112). In the aftermath of the war, the regime imposed by the victorious Spartans threatened not only craftsmen (many of whom were metics, or resident aliens), but also their citizen clientèle. Slaves were also in short supply, due to escape or military service (MacDonald 1981: 166). Furthermore, it would not have taken a very large exodus to seriously impact the pottery market (*ibid*: 167).

War, plague, occupation and emigration in the late fifth century correlates with our observations. In every analysis, including the motifs used, number of pots produced, the number of pots exported, the number of painters and the use of sub-techniques, we have seen that something happened in 425 to 375 BC that changed everything about Athenian pottery. Athens recovered in the 4th century, and so too did its pottery market, but it was very different than it had been before the Peloponnesian war (Macdonald 1981: 167). The increased use of lower quality wares meant that there was less reason to look to Athens for pottery, as there was less of a difference between local products and those that could be imported. At the high end of the market, fine painted pottery faced increased competition from outlying schools. Exports continued, as our results show, but the genie of fine figure-painted pottery could not be put back into the bottle of Athens.[25]

To return to our main point, it was against this background that we see Eros emerge as the last most popular motif on figure-painted pottery in 425 to 375 BC. As table 7.6 and figure 7.2 show, he did not begin to be copied in any great numbers until 475 to 425 BC, rose to a peak in 425 to 375 BC and then declined in 400 to 300 BC. Eros was common on red-figure cups, skyphoi, oinochoe, kraters and amphorae, but was especially popular on lekythoi and hydria (chapter 5, figures 5.25 to 5.54). Therefore, like Nike, Eros appears on vases used for dedications and gifts, as well as vessels not specifically related to the symposium such as hydria (as per Webster 1972: 98).

When considering all shapes and techniques together, our results show that the neutral model could not be rejected in 425 to 375 BC, and that therefore, overall, the popularity of Eros could be the result of random copying. However, the individual results for hydria and lekythoi in this period do reject the neutral model, and indicated a non-random

25 Of course, it is also possible that collectors and therefore scholars have simply been unenthused by later pottery because the painting on it is not as "good" as that of earlier periods. While figure-painted pottery was certainly on the decline, the fact that the Beazley archive groups all later pots into one category of 400 to 300 rather than 400 to 350, 375 to 325 and 350 to 300 is perhaps tellingly indicative of a lack of interest rather than difficulty in dating.

process at work which generated greater than expected diversity in lekythoi and lower than expected diversity in hydria.

Figure 7.6 shows the relative proportions of depictions of Eros and some related motifs which were popular in the late fifth century. The figure shows that Aphrodite was also more popular in 425 to 375 BC than in previous periods. It stands to reason that if Aphrodite is popular, then so too would be Eros. However, for every depiction of Aphrodite in our results, there are slightly more than three depictions of Eros. Eros could also appear in multiple forms in the same scene, identified as the Erotes, which we have treated separately from Eros himself. As the results show, the Erotes are much less popular than Eros but comparable in frequency to Aphrodite.

There are few clues to temporal changes in the popularity of Eros in previous research. Miller (1986) discusses Eros and the arms of Achilles as an important but rare scene, but having peaked in the early 6$^{th}$ century, Achilles does not appear in 425 to 375 BC at all. Barringer (2001) makes a thorough investigation of Eros in pederastic courtship scenes, but notes on page 73 that these fade out around 470, far before the peak in Eros depictions we see in the data. Woodford (1989) describes scenes in which Eros acquires the attributes of Herakles, with evidence from figure-painted pottery, sculpture, carved gems and poetry. Yet it cannot be this scene which is causing the popularity of Eros to spike in 425 to 375 BC, as Herakles is barely more popular in 425 to 375 BC than he was in the previous two time periods. It may be that, like Nike, Eros appears across a variety of scenes with a host of different characters, and that there is no single scene or event which specifically contributed to his popularity.

We are unable to link Eros or Nike to any particular scene or event which may have contributed to their extraordinary popularity in 425 to 375 BC and 475 to 425 BC respectively. While in both cases the popularity of the figures is not followed by the popularity of any other figure with which we would normally associate them, it is possible that they are appearing in many different scenes alongside a number of different gods, heroes and characters not included in our study, such as men, women and youths. We cannot be sure until we carry out a further study with our existing data to examine the frequencies of different combinations of motifs, rather than motifs on their own as in this study. Both Eros and Nike function as comments on the character or actions of figures in scenes in painting, showing other figures to be victorious or in love, either in themselves or in relation to third parties in the scene. These are ideas which would be difficult to portray in vase painting without the use of a figure to embody them. The themes are particularly appropriate for the lekythoi (and hydria in the case of Eros) upon which we find so many of their depictions. While we are again mindful of making unqualified, retrospective psychological assessments of the pottery consuming public, it seems likely that the generic, uncomplicated and generally positive nature of Eros and Nike must have contributed to their success, but even this description does not explain why so many of each are found within one time period. The possibility remains that they were the beneficiaries of a purely random process.

With this perhaps unsatisfactory conclusion we hope we have demonstrated the utility of a purely quantitative approach to motifs on figure-painted pottery, and shown how a focus on evolutionary processes can both confirm previous research and raise questions which are yet to be answered. In the next section we will return to the question of the change from black-figure to red-figure technique, and show how clues from motif frequencies can shed light on this poorly understood transition.

## 7.4 From black to red

### 7.4.1 Background to the transition

The transition from the black-figure technique to the red-figure technique in vase painting is widely regarded as a great turning point in Attic figure-painted pottery. Much more than a simple reversal of the black-figure scheme, red-figure represented a new way to organise colour fields. By replacing incised lines with brushed lines, red-figure gave painters increased flexibility, which they used to create scenes with greater naturalism, depth and movement than found in depictions that came before. The art historical implications of red-figure have been thoroughly (and repeatedly) covered elsewhere. Here, we will examine how the transition came about and what our results contribute to an understanding of this event.

To review, the red-figure technique was developed in Athens between 530 and 520 BC (Williams 1991: 286). Signatures on the earliest examples of the technique suggest that Nikosthenes, Amasis or Andokides may have been its inventor (Williams and Burn 1991: 104), though they may just as easily have been among the earliest to copy the technique from another unknown potter or painter. Nikosthenes and Andokides were potters as well as painters, and have both also been credited with inventing the white ground technique around 530 BC (Mertens 1974: 91). Williams also raises the intriguing possibility that red-figure may have been requested by a customer (Williams and Burn 1991:103). There is no way of addressing this possibility, but it would not be the last time that an innovation attributed to an artist arose from the suggestion of a client.[26]

Because we do not have space to include an analysis of the outputs of painters, and because the dating of pots is in large 50 year groups,[27] we are unable to add to the debate about the specific identity of the inventor of red-figure. We can, however, state that our evidence supports the idea that painters were experimenting with techniques in the two date categories which overlap the last half of the sixth century.

### 7.4.2 The invention of red-figure

The question immediately then arises as to the purpose of these experiments. Many explanations have been proposed, but all can be grouped into four general categories: art historical necessity, the imitation of other materials, the demands of the export market and general statements which propose no precise function.

To address art history first, it is very common to read that the red-figure technique was invented because of some "internal necessity of the craft", as Robertson (1992: 9) puts it. This is made explicit in statements such as "[t]he limitations of the black-figure technique, particularly the unrealistic colour scheme, began to hinder artists who strove for ever richer and more varied representations" (von Bothmer 1972: 4) and that artists required "a medium more subtly expressive" (Cook 1997: 44). This view, however, can only be supported retrospectively, rather than at the point of invention. As Williams points out, the earliest examples of red-figure were simple and contained neither relief lines nor interior markings (Williams 1991: 286). It was not until the generation after the invention of red-figure, with the painters dubbed by Beazley as the "Pioneers", that red-figure scenes begin to show any increased sense of naturalism or flexibility (*ibid.*). It is therefore difficult to say that the catalyst for the invention of red-figure was an art historical need, when the inventors themselves did not produce such depictions. We do not dispute the achievements of red-figure painters, but to explain away the transition from black-figure to red-figure as natural progression implies that decoration has some

26 Indeed Damien Hirst's famous shark in formaldehyde "The Physical Impossibility of Death in the Mind of Someone Living" of 1991 is rumoured to have been the idea of Charles Saatchi, his most prominent patron at the time.

27 Dating is another thing that could be improved through public participation in the database. See conclusion for details.

kind of goal in mind towards which artists unconsciously struggle. Previous research (*e.g.* Sugiyama 2001) suggests that we are naturally pre-disposed to prefer information in the form of narrative, so such a story of the progress of art in vase painting matches our expectations of how change happens and what it is for. From this perspective, it is no surprise that the narrative of red-figure as a further step in artistic progress has gone unquestioned for so long.

The second possible explanation for the invention of red-figure is that it was done to better imitate light on dark schemes found in other media, such as textiles, relief sculpture or metalwork. There has been much opposition to these ideas, as Williams summarises (Williams and Burn 1991:105-106). It seems unlikely that a craftsman working in another media, such as relief sculpture, could have moved to Athens and immediately gone to work in a potter's shop and there spontaneously invent red-figure technique (*ibid.*). However, many crafts during this period were interdependent (such as painters who worked with sculptors and carvers), so it is remains a possibility. It is also possible that a potter could have seen a light on dark relief or textile pattern and copied it in the form of red-figure. Like many proposed reasons for the invention of red-figure, this is a difficult hypothesis to refute. Both light on dark and dark on light schemes existed in textiles and relief sculpture long before red-figure was invented, and there is no obvious juncture at which the leap from one medium to another could have been made.

There are, however, some enticing parallels between red-figure and metalwork. Vickers and Gill have argued extensively that red-figure was developed to better imitate the colour scheme of gold figured silver metal ware (Vickers 1985, Vickers 1987, Vickers & Gill 1994). This argument has not gained widespread acceptance. The main difficulty is that very little metal work has survived. We can only make tenuous estimates of how much was in circulation when red-figure was invented, and how many consumers, therefore, would recognise the technique as a copy of the gold figured scheme. A much larger problem, however, is the lengths to which Vickers and Gill go to show that everything about figure-painted pottery was derived and that nothing or very little came from the potters and painters themselves – not even the signatures, which are supposed to be copies of the names of the "real" artists who produced the metal originals (Vickers and Gill 1994: ch. 6). "[O]nce one has been alerted to the possibilities of metallic inspiration, there is no point at which it is reasonable to stop" (Vickers and Gill 1994: 133). Indeed, this is the problem with the presentation of the argument. All researchers of figure-painted pottery should recognise that our present understanding has been heavily influenced by centuries of connoisseurship, but this does not mean the entire field is a fraud.

One strand of the debate has taken shape in an ongoing exchange about the role of figure-painted pottery as an export – whether it was intentionally exported in bulk or whether it was crammed into the empty space around more precious cargo as a bonus (Boardman 1988a, Boardman 1988b, Gill 1988b, Gill 1991, Osborne 1996b). Regardless of how it was transported, it appears that pottery was disposed of on the secondary market through regular, organised channels not dissimilar to today's eBay shops which specialise in second hand luxury branded goods. Pottery was not valuable enough to warrant dedicated shipments, but it would never hurt to have figure-painted pottery available for sale when delivering a shipment of other goods.

However the second hand market could not have been strong enough to actually create the demand for red-figure pottery, as Boardman states. While it is true that the sum of pots found outside Athens is many times larger than those found in Athens, this should not be taken as evidence of export being the primary market, or that red-figure was invented as a "new line for the growing export market" (Boardman 2001: 79). There is no need to invoke the idea that foreign buyers demanded something new from Athenian potters, as all evidence suggests they were perfectly happy with what they were getting prior to the invention of red-figure. Furthermore, as discussed in the previous section, it was not until after 425 BC that imported Athenian pottery began to face substantial local competition, so it is difficult to see who would have demanded this "new line" and by what mechanism.

In fact, even the domestic market shows no sign of requiring a "new line". In the 525 to 475 date category, our sample includes just under 8,000 black-figure pots. This is the largest sample for any single technique in any date category from 625 to 300. The largest sample in red-figure occurs in the 475 to 425 date category, with just under 7,000 pots. Clearly there was no need to revitalise the pottery market with a new technique. We do, however, see this in the 400 to 300 date category, in which outline and added colour are much more popular than in previous date categories. This follows the collapse seen in the 425 to 375 date category, so it is reasonable to suggest that potters and painters were attempting new things in the face of a changed market. This is supported by Fitzhugh's assertion that when conditions change, the payoff for invention as opposed to copying increases (Fitzhugh 2001). There was no such crisis in the pottery market in 525 to 475 BC, so we cannot conclude that red-figure was invented to respond to a new challenge or uncertainty.

It is also possible that red-figure appeared in 525 to 475 as a direct result of the very large sample size generated in this date category. Each of the thousands of pots produced in this period was an opportunity for mutation, with each additional pot representing an additional chance for something new to appear. This view is supported by some authors, though their reasons are not well defined. Sparkes describes red-figure as having been a product of the "creativity of the *Kerameikos*" (Sparkes 1996). Williams states that:

> "my own personal feeling is that it was a period when there were many technical experiments in the air, including the invention of white ground and the so-called Six technique, some perhaps prompted by the commercial acumen of a potter like Nikosthenes, others by the artistic instincts and searchings of painters such as Psiax, and that the red-figure technique was the experiment that in the end proved most successful" (Williams1991: 286).

This is an observation, not an explanation. Yet we find this description to be sympathetic with our results.

The last half of the sixth century was a period of experimentation in techniques, but not motifs. When red-figure was invented, the old motifs such as warriors, sphinxes and sirens, had reached a state of equilibrium, while the new motifs such as Nike and Eros had not yet appeared in large numbers. After the transition around 560 BC in myths used by Attic vase painters (as described by Shapiro 1990: 115), the overall sample of all shapes together shows that the three periods 550 - 500, 525 - 475 and 500 - 450 have a very low mutation rate (1%) and a very low drift rate (between 0 and 1% motifs not copied) (as shown in figure 4.11.7). Furthermore, as shown in figure 4.11.2, after reaching a peak in 575 - 525 BC, the number of motifs in use in black-figure actually fell between the periods 550 - 500 BC and 525 - 475 BC, as older motifs were winnowed out as part of the transition described by Shapiro. The number of motifs in use in red-figure rose during the same period, but the frequency of these motifs was very low. In 525 - 475 BC, turnover rate of motifs, as shown in figure 5.58, was also tightly constrained, with all motifs changing no more than +/-5% from their levels in 550 - 500 BC.

Our neutral model analysis confirms that motifs were not the main focus during this period. As described in chapters 4 and 5, we tested the diversity, distribution and turnover rate of motifs. Out of all 10 of the date categories analysed, diversity is lowest in 550 - 500 and 525 - 475 BC. In fact, diversity is so low during these periods that we can reject the neutral model in both date categories, as shown in table 4.12.7, in favour of conformity. The distribution of the motifs, however, as shown in the r-squared test, did not reject the neutral model in 550 - 500 and 525 - 475 BC, as shown in table 4.12.8. The test for turnover rate of top y motifs (as described at the end of chapter 5), also did not reject the neutral model during these periods.

These results tell us that the motifs observed in 550 - 500 BC and 525 - 475 BC were distributed according to a power law and that their turnover rate was neither higher nor lower than would be predicted by the neutral model. The diversity of the motifs, however, was lower than expected under conditions of neutrality. Together these results show that motifs during these periods had reached a stable plateau. The overall pool of motifs is smaller than expected given the number of pots in the sample, but are distributed and turning over at a rate that is not inconsistent with random copying. These results support the overall conclusion that motifs were not the focus of innovation in 550 - 500 and 525 - 475 BC. Had this been the case, we would expect to see greater than expected levels of diversity and turnover rate. It is therefore possible that instead of diversifying subject matter, potters and patrons were looking for new techniques instead.

Yet, if this was the case, then why was experimentation in techniques confined to this one period, and why did it not happen again until the pottery market changed after 425 to 375 BC? In the course of the study we have seen hundreds of innovations in motifs, and there are many more we could not include, such as the differences in the way each motif is executed. Yet we observe only 8 techniques and sub-techniques in more than 40,000 pots spread over 10 date categories covering 325 years. This tells us that there were constraints on innovation in technique, such as the demands and expectations of the market. Each patron could have brought their own tastes and preferences to the selection of a motif, but it would take an exceptional client to demand or accept an entirely new technique.

### 7.4.3 More drift or more selection?

We propose that the transition from black-figure to red-figure can best be understood as two distinct events: invention and diffusion. It is almost impossible to meaningfully address the act of invention itself, as described in section 7.4.2 above. Red-figure may have been invented for any one or a combination of the reasons proposed. Without some extraordinary new evidence, it is difficult to imagine circumstances under which any current theory can be falsified. However, as we have discussed throughout this research, it is not our goal to understand the specific ingredients of the single act of invention which became the red-figure technique. Even if we could perfectly capture the life of the painter who made the very first red-figure vase, we would be left only with a description of a single event. Instead, it is the spread of the use of red-figure that is of greater importance. If we can understand the mechanisms by which the innovation of red-figure spread through vase painting, then we are in a much better position to understand other innovations in other contexts, both today and in the archaeological record.

The question is whether the spread of red-figure and its eventual replacement of the black-figure technique occurred more due to selection or more due to drift.[28] The data show that the change from black-figure to red-figure was a near-total replacement, but it was not immediate, and appears to have occurred in a drift-like fashion. Recall that drift is the tendency, in the absence of innovation, for a population to carry only one version of a variant. As shown in figure 6.2, we see that by 550 to 500 BC, all 8 of the techniques and sub-techniques observed in this study had appeared at least once. Yet after this, no new techniques or sub-techniques appear, and by 475 to 425 BC, only two techniques appear in our sample at high frequency: red-figure and white ground. It is not until the last period of the sample, 400 to 300 BC, that the frequency of any sub-technique increases again. It is therefore entirely plausible that red-figure became the dominant variant for technique simply through copying and a lack of further innovation. At the population level, the process under this scenario would have been that each time a pot was made, a technique was chosen at random from the 8 available. Each time red-figure was selected, it increased the probability that red-figure would be used again the next time a pot was made, while at the same time slightly decreasing the probability that other techniques would be used. Over enough generations (recall that each pot is a generation) red-figure could emerge as the most popular variant by chance alone. Had there been further innovation in techniques, each new technique would have the potential to counteract the accumulating frequency of red-figure, but this is not what happened.

However, rather than selecting randomly at the population level, painters may have been actively choosing red-figure over other possibilities. This would have the effect of not only increasing the frequency of red-figure overall, but also decreasing the frequency of

28 As per the discussion in Shennan and Wilkinson (2001), we see drift and bias as representing ends of a continuum of selection, from very weak to very strong, rather than the absolute dichotomy proposed by Dunnell (1978).

other possibilities. This is what we see in the data, which clearly show an unbroken increase in the number of red-figure pots in the sample from its invention around 525 BC to its peak in the date category 475 to 425 BC. The number of black-figure pots in the sample over the same period shows the opposite trend, while other techniques, with the exception of white ground, are not copied in large numbers beyond 525 to 475. However, drift alone, without any form of selection, could produce exactly the same pattern. As we have seen in many of our motif samples which appear to produce counter-intuitive results, it is not possible to evaluate whether the neutral model applies or not simply by looking at the data.

From the frequencies alone we could plausibly support either hypothesis.[29] The difference between the two scenarios rests in whether we can realistically consider the difference between techniques to be value-neutral. In our main results we have considered each motif to be functionally equivalent at the population level, but the same may not be true of techniques. Certainly the difference between either technique and coarse ware, or a non-figurative technique such as black glaze, is not value-neutral.  Furthermore, neither technique affects the function of the pot as a vessel. However, from the point of view of a painter, the function of figure-painted pottery is to be sold, and any feature which increased this possibility is likely to have been selected. If one technique had the effect of, for example, increasing sales or the painter's reputation, then that technique will be favoured. When a variant is not neutral, we would expect the choice with the highest payoff to become the most popular (Bentley *et. al.* 2007: 157). Given the close working conditions of the *Kerameikos*, finding out what was generating the highest payoff would have been very easy. In this scenario, the “progress” of red-figure was not down to artistic visionaries or slavish copiers of other materials. It was the result of competition between producers looking for an edge. The result of this would be biased transmission.

It is certain from the frequency distributions that producers and consumers of fine figure-painted pottery also considered red-figure to be superior to black-figure. Perhaps they preferred it for the improvements in naturalism that it allowed, or perhaps they preferred it because it resembled the colour scheme of gold figured metalwork, or perhaps simply because it was new and different from what had come before (though this would not

29 We were unable to carry out a test of the neutral model using techniques as a variant. Given that so few techniques were invented for such a large number of pots, the mutation rate is actually extremely low. When very low mutation rates are combined with very large sample sizes as parameters, the model has almost no chance of rejecting the neutral hypothesis. This limitation does not affect the rest of our samples, as mutation rates are generally much higher and sample sizes smaller.

explain why it was preferred against other innovations in technique from the same time). It is unrealistic to assume that everyone who adopted the new technique was doing so for the same reasons, and the precise nature of the preference is both irrelevant and ultimately inaccessible. If the painters were available for interview today we do not believe a coherent single reason would emerge, so we should not attempt to impose one. What matters is that the preference can be observed in the frequencies of techniques, and that it was strong enough to cause an almost total replacement of one technique with another. We should bear in mind, however, that it would not have taken a large advantage for red-figure over black-figure to produce these effects. A small but consistent advantage would be enough, when iterated over the thousands of pots produced in Athens each year. About 50 years – two working generations of humans – passed between the introduction of red-figure in 525 BC and its peak frequency in 475 to 425 BC.

The situation was very different for white ground. White ground emerges slightly earlier than red-figure, but never becomes popular overall. However, if we look at the frequency of white ground vases by shape, we see that by 475 to 425 BC, 96% of all white ground vases are lekythoi. If we look at the distribution of the white ground technique within lekythoi (figures 7.7 and 7.8), we see that in 500 to 450, a majority of lekythoi were still being made in black-figure. At the same time, 24.92% of lekythoi in our sample were made using the red-figure technique and 19.02% were made using the red-figure white ground technique. In the next date category, 475 to 425 BC, the percentage of red-figure lekythoi has increased to 67.28%, while 29.28% are red-figure white ground. In the next date category, 450 to 400 BC, white ground lekythoi surpass red-figure lekythoi, with 44.23% found in red-figure and 55.30% in red-figure white ground. This indicates that as soon as red-figure became widely adopted, in 500 to 450 BC, both red-figure and red-figure white ground were considered almost equally optimal for use on lekythoi. The only exception to this trend is 475 to 425 BC, when red-figure was twice as popular as red-figure white ground, but overall the pattern holds until 425 to 375 BC, when white ground all but dies out as part of the great shake up of the fine figure-painted pottery market discussed in the previous section.

These frequencies show us that the selection criteria for techniques on lekythoi were different than for other shapes. A similar situation existed in Panathenaic amphorae, which continued to be made in black-figure regardless of the development of red-figure. More importantly, the results for white ground lekythoi show that it was possible to have multiple optimal techniques for a single shape – as red-figure and white ground appear to have been equally acceptable alternatives. Given the fragility of the white ground technique, it would certainly be a sub-optimal technique to use on a shape which would be used and handled regularly, and therefore does not appears at very low frequency on shapes related to the symposium, such as cups, skyphoi, oinochoe and kraters. These shapes do, however, show very strong bias towards the red-figure technique.

### 7.4.4 Mechanisms of transmission

Previous research treats the increase in uptake of red-figure as a self-evident, inevitable follow on from the invention itself. However, invention alone is not enough to ensure popularity or even survival. The variant must be copied by others, and this is as true for the invention of a new technique as it is for all of the hundreds of motifs we examined earlier in this research. As Boyd and Richerson describe, there are two stages to maintaining cultural variation: transmission and persistence (Boyd and Richerson 2005: 56). Transmission is the ability of a variant to be copied, and persistence is the ability of those copies to then be copied by others. A technique that cannot readily be learned by others cannot be transmitted, and a technique will not persist if these copies do not become models for further copies. Clearly the red-figure technique was both transmitted and persistent, with each new copy steadily increasing the frequency overall. With the exception of white ground, other sub techniques invented around the same time as red-figure were briefly transmitted but did not persist.

The usual narrative for the transmission of red-figure is that it was invented, for whatever reason, then was taken up by the "Pioneers" and then was adopted by nearly all painters as the dominant technique for fine figure-painted pottery. In this process, the Pioneers occupy a special role, in which, as their name implies, they demonstrated the decorative potential of red-figure. This implies that some form of biased transmission took place, perhaps following the model of prestige biased transmission in which the successes of the Pioneers were copied by others. Henrich and Gil-White (2001) have described mechanisms by which the variants used by prestigious individuals are preferentially copied by others. It is difficult to evaluate whether prestige played a role in the transmission of red-figure, as we have very little evidence of the status of painters, and what evidence there is does not form any picture of differential status based on techniques employed.

Another possible mechanism for the transmission of red-figure, and indeed for the transmission of popular motif variants, is the "influentials" hypothesis, which is often used to describe information flow in modern populations (Katz and Lazarsfeld 1955, Merton 1968). In this model, information is copied preferentially from "opinion leaders". These are not leaders in the traditional sense, but rather the "well connected". In his recently popular book "The Tipping Point", Gladwell describes such people as "mavens" (people who seek out and accumulate new information) and "connectors" (people who bring other people and new ideas together) (Gladwell 2001, ch. 2). Gladwell would look at the spread of red-figure and hypothesise the existence of both "mavens" and "connectors" early in the history of red-figure, people who would both copy and communicate the idea of red-figure, until it became the epidemic we see in the data. In this view, the Pioneers play the role of "early adopters", who take the risk of investing time and talent in a new and unproven technique (Moore 1991). Resemblance to gold figure metalwork, light on dark schemes in other media and enhanced naturalism would all increase red-figure's "stickiness" (Gladwell 2001, ch. 3), causing it to be remembered (the essential quality of persistence described by Boyd and Richerson, above) and therefore copied.

As seductive as such descriptions of change are, there are other, simpler explanations of transmission which accurately reflect observed events. Watts and Dodds (2007) have recently called into question the role of "influentials" in spreading ideas. Using a model of the spread of a variant through a population, they are able to explore the difference between highly connected "influentials" and average individuals. Their model of influence is particularly appropriate for our case study as it excludes the possibility of increased influence through media outlets (*ibid.*: 447), which did not exist in Athens. Given that most fine figure-painted pottery was used in social settings, a model predicated on person to person interactions is the most plausible for the given situation. Moore (1991) and Gladwell (2001) would predict that influentials should start trends (frequency cascades) more readily than average individuals. The results show that "influentials" do have more impact than average individuals, but they are also able to show that such special people are not necessary for cascades to occur (Watts and Dodds 2007: 446). Watts and Dodds conclude that "in focusing on the properties of a few 'special' individuals, the influentials hypothesis is in some important respects a misleading model for social change. (Watts and Dodds 2007: 454). Cascades occur, they argue, not because of a few people influencing everyone else, but rather on account of a “critical mass of easily influenced individuals influencing other easy-to-influence people” (*ibid).*

In this regard, Watts and Dodds (2007) directly refutes one of the key ingredients of Gladwell's “tipping point” (Gladwell 2001). While Gladwell privileges special “connectors” in bringing ideas to the fore, Watts and Dodds show that the ability of “influentials” to enhance epidemics is less than expected. “Thus, to the extent that particular individuals appear, after the fact, to have been disproportionately responsible for initiating a large cascade or sustaining it in its early stages, the identities and even characteristics of those individuals are liable to be accidents of timing and location, not evidence of any special capabilities or superior influence” (*ibid*.). Some forest fires are many times larger than average, yet no one would claim that the size of a forest fire can be attributed to the exceptional properties of the spark that ignited it or the tree that was first to burn. There are many factors which are far more important, and when the conditions are right, “any spark will do” (*ibid.*).

The evidence of the neutral model and individual motif frequencies suggests that the “any spark will do” model describes Athens in 525 BC. The conditions were right for a change to occur, and though several sparks were in the air, only red-figure fully ignited. According to the model of Watts and Dodds (2007), we should not seek to ascribe special qualities to the “Pioneers”, but rather we should only note that they were first on the scene. Furthermore, not only is it incorrect to look for special qualities in the people who initiate cascades, it may also be wrong to ascribe special qualities to the variants themselves. Variants which become popular may simply happen to be in the right place at the right time – indeed this is a key prediction of the neutral model itself. We do not deny the obvious advantages of red-figure over black-figure as a decorative medium, and, as above we believe the evidence supports the conclusion that red-figure was selected. However, there is no evidence that this was the only variant which could have become popular at the time. Had events passed differently, we could just as easily be studying some other technique and wondering why red-figure never caught on.

# Chapter 8

# Postscript

## After the Beazley archive

This project has applied a new theory of cultural diversity to an old collection of ancient objects. Our practical accomplishments include the production of a usable data set of figure-painted pottery and the development of a technique for comparing the predictions of the neutral model with real world data. We have shown that chance alone can explain the distribution of motifs on some shapes at some times, and that it is not always necessary or correct to ascribe purposeful intent to the chance events of history. We will now conclude with some suggestions for the direction of future research in the quantitative analysis of figure-painted pottery.

### 8.1 Whose muse?

In a recent collection of essays from which this section takes its title, museum professionals address questions about the purpose of museums in contemporary society (Cuno 2004). Large cultural institutions must satisfy the demands of preservation, entertainment, academic inquiry and public service, and will inevitably be found lacking in one or more of these areas as resources are divided. Neil MacGregor, director of the British Museum, asks (MacGregor 2004: 27): "how, for whom, and for what purpose do we present our collections?" We might well ask the same question of the study of figure-painted pottery. As the back cover summary of Rasmussen and Spivey (1991) states: "An ancient Greek vase is a difficult object for the non-expert to come to terms with. Faced with rows of undifferentiated pots, he is at a loss as to where to begin."

The explanations given by experts vary from quaint to idealistic. Writing in the 1950's, Richter imagines her non-academic audience to be well heeled tourists, as an understanding of Greek art provides context for the sights of Greece (Richter 1959: 11). Vickers and Gill have effectively described the entire field as a scheme to increase revenues of auction houses and collectors (Vickers and Gill 1994). Boardman reaches out to the "student, connoisseur of ancient art or lover of fine drawing" (Boardman 1975: 7) and proposes that the study of figure-painted pottery provides a "subtle but direct commentary on the attitudes and preoccupations of the day, as well as a great deal of engaging narrative" (Boardman 2001: 7). Then there are all the other fields which draw information from figure-painted pottery, identified by Boutler as studies of the iconography of myths, understanding of Greek history (particularly colonisation), dramatic and religious practice, "but the evidence must be used with caution" (Boulter 1981: 106).

Such "warnings" against the misuse of evidence from figure-painted pottery are common. Carpenter states that "an image is open to an almost infinite number of interpretations by a viewer unfamiliar with the culture or the visual tradition" (Carpenter 1997: 8). Indeed this is true, and the degree to which painters were depicting scenes from life or imagination is a source of much debate (Neer 2002). When is a woman weaving just a woman weaving, and when is it Arachne? Does a high frequency of weaving images indicate that this was a common practice, or does it tell us that the myth of Arachne was popular? Or perhaps some of both, as is so often the case? There are no easy answers to such questions, and an argument must be made if the scene is to be claimed exclusive to one side or the other. In order for the field to advance, however, such debate should be encouraged, not closed off to non-experts who might get things wrong. The experts, as we have seen, get things wrong too.

As Ridgway notes, the field of vase painting and pottery "has become so specialised as to be almost the exclusive provenance of the classical archaeologist or iconographer. At an advanced level, few even among the archaeologists can communicate intelligently; yet the information to be derived from vases is of increasing importance to all, now that more and different questions are being asked of the material"(Ridgway 1986: 17). With or without the approval or participation of classicists, the material of figure-painted pottery is going to be used in studies of all sorts, as the value of the data sets such as that used in this study becomes recognised. Indeed, the very survival of classics departments in some universities may depend on such new and innovate applications of data. Houston (2003) paints a very gloomy picture of the future of classics in the face of increased competition from “for profit” universities, in which learning for its own sake is not an option. It is up to classicists themselves to consider “ways that Classics can position itself to thrive within this new world. What can we offer students in a business-oriented environment?” (Houston 2003: 287). If classicists don't speak up, claim a stake and demonstrate efficacy, then others will make the judgements on their behalf, and possibly not in the direction desired (*ibid.*).

Our response, as shown in this study, is that the history of  Greek figure-painted pottery is an unrivalled historical example of how much diversity can arise from copying alone. While there are of course important differences between the structure of the Greek economy and our own, we know of no better data set with which to explore the implications of copying, bias and innovation, each of which are behaviours in which people are engaged today.[30] This is by no means the only approach. We hope our study will encourage others to follow on with further projects employing other new techniques, such as phylogenetics and advanced network models. If the evidence from figure-painted pottery is “misused” in such research by “non-experts”, then it will be up to the “experts” to respond. The answer is not to close off access to the evidence itself, for, as Houston warns, this may be a shorter term solution than expected.

## 8.2 Open access

One of the key predictions of the neutral model is that if a variant is copied it increases the chances of it being copied again the next time there is an opportunity to do so. Each time there is a copy, there is a chance for innovation. We have seen how these processes may have contributed to the invention and popularity of the red-figure technique. What would have happened if the inventor of the red-figure technique had licensed the process, and demanded a fee from everyone who wanted to use it? There are two possibilities. The first is that he would have become rich on the back of red-figure's success. The second, and perhaps more likely outcome, is that painters would simply do something else, and we never would have known that red-figure even existed. If a variant, whether a technique or an idea, is to survive, it must be copied. Anything that can be done to eliminate barriers such as the hypothetical red-figure license fee will only increase the

30 Including you, by reading this.

likelihood of copying. This does not mean that work should not be rewarded financially or that protections such as license fees and copyright are undesirable. It simply means that when deciding how to release an idea, the need to be copied must be balanced against the need to be remunerated. Ideas that are not copied die. This is clear from the frequency distribution of techniques in Athenian pottery.

It is therefore ironic that one of the biggest barriers to the copying of ideas and innovation is "Athens" itself. Launched in 1996, the Athens authentication system provides access to hundreds of scholarly journals. Like JSTOR, Project MUSE and other resources, it is a system in which a fee is paid by an institution in order for its members to have access to journals and archives. These services are invaluable for any serious scholarly research, but the fact they are unavailable to individuals who are not members of participating institutions is an impenetrable barrier to the copying of ideas. The cost of subscribing to individual journals is impossibly high. In fact the costs are so high that many libraries are now having difficulties paying for the subscriptions. This is known as the "serials crisis" (Panitch and Michalak 2005), in which the increase in cost of subscriptions outstrips the budget available to the library. As described in this white paper, the cost of journals in science, technology and medicine are far higher than those in the arts, but when budgets are cut by dropping subscriptions, it is the lesser used humanities titles that are likely to disappear first (*ibid.*).

This problem will persist and worsen for as long as the outmoded model of printed and bound journals on shelves is maintained. It has long been predicted that electronic journals will replace paper journals at some point:

> "Movies-on-demand will mean wide availability of networks with speed in the hundreds of megabits per second. If your local supplier can get you the movie of your choice at the time of your choice for under $ 10 (as it will have to, in order for the system to be economic), then sending over the 50 MB of research papers in your specialty for the last year will cost pennies. Scientists might not like to depend on systems that owe their existence to the demand for X-rated movies, but they will use them when they become available" (Odlyzko 1995: 50).

In the last 14 years movies on demand, of all sorts, have certainly become available and, as predicted, it is largely thanks to this that consumer networks are getting faster all the time. The cost of accessing journals, however, has not been reduced to pennies, and some have more than doubled since the above prediction was written (Panitch and Michalak

2005). It is no exaggeration to say that this is a direct result of the monopolies on information enjoyed by academic publishers. As Wyly reports, Reed Elsevier's 1997 filing with the U.S. Securities and Exchange Commission (20-F) informs investors that the company is increasingly “concentrating on high value-added areas of 'must-have' information and significantly reducing its exposure to the consumer markets” (Wyly 1998:6) . In other words, Elsevier can charge high prices without fear of competition through consumer choice. Needless to say none of this income is returned to the producers of the research themselves.

These issues of cost and access are directly relevant to the problems facing the humanities and the study of figure-painted pottery specifically. We can hardly chide “non-experts” for getting things wrong while at the same time relying upon and supporting a closed literature. When academics and departments must justify their existence or staff levels by demonstrating relevance, it is not acceptable to place the bulk of academic output beyond the reach of the public. Artificial barriers such as “moving walls” serve only the interests of the publisher by ensuring that a costly print subscription be maintained, and mean that citations and transmission of academic research is delayed by the arbitrarily imposed period. As Boyd and Richerson (1985) have described, the vital ingredients of cultural transmission are the ability of an idea to be copied and the presence of individuals to do the copying. The current model of academic publishing denies us both.

As Wyly describes, “when a researcher takes on the maze of literature databases, the frustration of shrinking local library collections, the long-delayed document delivery services and the shocking copyright fees, it rapidly becomes clear that there has to be a better way, given that the author and the reader share the desire to communicate” (Wyly 1998: 7). And indeed, there is a solution, and that is the open access journal. The Budapest Open Access Initiative defines an open access journal as follows:

> “By 'open access' to this literature, we mean its free availability on the public internet, permitting any users to read, download, copy, distribute, print, search, or link to the full texts of these articles, crawl them for indexing, pass them as data to software, or use them for any other lawful purpose, without financial, legal, or technical barriers other than those inseparable from gaining access to the internet itself. The only constraint on reproduction and distribution, and the only role for copyright in this domain, should be to give authors control over the integrity of

their work and the right to be properly acknowledged and cited." http://www.earlham.edu/~peters/fos/boaifaq.htm#openaccess

As the BOAI describe, this initiative is compatible with all the traditional protections of copyright and does not preclude the possibility of priced sales of printed versions of the same work. It seeks only to connect readers with literature, which should be the goal of all content delivery systems.

Thousands of open access journals are indexed by the Directory of Open Access Journals, Public Library of Science and arXiv.org. A number of journals relevant to classics have already appeared. Ober *et. al.* (2007) describe the founding and success of the Princeton-Stanford Working Papers in Classics, an open access system for distributing pre-prints of scholarly works. The Bryn Mawr Classical Review, Stanford Journal of Archaeology and Journal of Classical Studies are all free for users. In none of these is the user required to agree to a license for every pdf downloaded (as in JSTOR), nor are the pdfs copy protected in an attempt to prevent transfer between machines (as in the Cambridge University Press “Classical Review”).

These examples, and thousands like them from other fields, show that open access publishing remains compatible with robust peer review. From the point of view of the reader, editor, reviewer and author, the process is very much the same. It simply cuts out the middleman to increase the flow of ideas. As Panitch and Michalak (2005) describe, we do not think it is possible to change the existing policies of publishers, as they simply do not recognise the implications of the post print world. For example, Cambridge Journals have added social bookmarking features to their online journals, yet all but a few token articles (access to which is blocked by a full page registration form) are behind a paywall, rendering the social sharing of links impossible. Instead, we must simply support, cite and most importantly contribute to journals who follow the open access model. In order to influence the easily influenced, to follow the model of Watts and Dodds (2007), we must make influence easy.

## 8.3 Implications for the Beazley archive

The relevance of this discussion to our study is clear. Recall that in our methods discussion, we reported that we were denied access to the raw data of the Beazley archive for “copyright reasons”. This forced us to undertake months of unnecessary work in order to recreate the archive from captured search results. The resulting data would have to have been cleaned regardless, but it would have been preferable to spend more time doing that and less time parsing search results into fields. We applaud the efforts of the Beazley archive for recently allowing access to its database without registration, and recognise that the creation of the database itself in the early 1980s is a fine example of early adopting, but now it is time for the Beazley archive to take another step forward.

There are two things that the Beazley archive must do if it is to be a useful resource for quantitative research. First, it must be rebuilt on new architecture. We do not know if it is a fault of the XDB system the Beazley archive uses or its implementation, but the current search system is not effective for any serious quantitative inquiry. Researchers require the ability to form complex queries using operators, and they need search results to be returned in a timely manner, rather than stalling and timing out as is often the case in the current system. MySQL would be an ideal choice as it is fast, reliable and most importantly free, and the skills to run it exist at a high frequency in graduate student populations. Second, the new architecture must include an option to export search results in recognised downloadable formats such as tab separated text, csv or as a direct sql dump. From this, researchers can then conduct their work on a local system, using queries too complex to enter in an online form, as we did in this study. According to one programmer with whom we collaborated in our research, to build a new Beazley archive as we describe here would take no more than two to three weeks.

These are essential steps, and cannot be circumvented if use of the Beazley archive is to grow. There is much more, however, that could be done. The watermarking and restriction of use on photographs in the archive must be abandoned. At present, all photographs contained in the Beazley archive are watermarked with the user name, user's IP address, copyright, date, license number and a statement saying that "This image is not for publication. It is registered & *fingerprinted*" (emphasis ours). This warning takes up about a third of the image surface. The license number does not even refer to the database vase number, thus ignoring the one feature of the "fingerprinting" system which would actually be of use to users. The images themselves are low quality bitmaps, which take a very long time to access, not only because the system itself is slow, but also because the watermark must be generated. We cannot imagine what revenue the Beazley archive thinks it is protecting by forbidding the reproduction in print of a black and white 500 pixel by 500 pixel 8 bit bitmap, but we can assure them that such images would be worse than useless for printed publication. We realise that the inclusion of this watermark was probably part of the original negotiation between the archive and the contributing museums, but it is time to look again at this feature, as it is currently impossible to check the descriptions against the images in any quantity.

This would be a necessary component if the Beazley archive were to take a truly ambitious step and begin the production of an interactive, wiki-like pottery archive. As we described in chapter 3, the data in the Beazley archive is in very poor condition. There are numerous errors, misspellings, omissions, incomplete records and general garbage, which is to be expected of a database that has been in continuous use since 1979. All of these reduce the utility of the database as a whole. Though we were able to clean our local copy of the Beazley archive over a period of  months, to clean the entire database would be a vast undertaking and is therefore unlikely to ever be done. We propose that an easy way to solve this problem would be to create a wiki of pottery from the existing database. In such a system each pot could be given its own page. Users could then read these pages and submit corrections when incorrect entries are observed. Administrators could then approve, reject or request more information about these corrections, and when satisfied could add them to the entry. Such a system could also go beyond mere corrections, and allow users to look at images of pots and add tags to the entry, in order to build up records of information which currently is not recorded, such as “multiple ground line” or “frontal eye” and so on.

There are many scientific and cultural enterprises already exploiting the “cognitive surplus” (Shirky 2008) available via the global internet today. The Galaxy Zoo project ( http://www.galaxyzoo.org/ ), for example, invites users to look through thousands of astronomical images and classify any galaxies they find. Dozens of biodiversity projects ask individuals to contribute observations of local wildlife. Such “citizen science” is able to accomplish large scale tasks which would be too costly or difficult to carry out independently. Cleaning and tagging the images and records of the Beazley archive is exactly the sort of project that could take advantage of the spare time of amateurs. While this proposal may sound outlandish, this project or something like it will have to be undertaken for the Beazley archive to become a serious data source. The alternative is to do nothing, and allow the Beazley archive to effectively be used only for looking at single vases. To do this would be an act of negligence not only to the Beazley archive itself but to the study of figure-painted pottery as a whole, as it will deny the promise held by quantitative approaches to the material. It is better to have the data “misused”, to quote Carpenter, than to not be used at all. As we have described throughout this study, innovation can only occur when there are opportunities to copy and interact with ideas. This clearly worked well for figure-painted pottery in ancient Athens. It can also work for us today.

# Bibliography


Aberson, C. 2002. Interpreting null results: improving presentation and conclusions with confidence intervals. *Journal of Articles in Support of the Null Hypothesis* 1:36-42.

Ackermann, H. C., and J.-R. Gisler. Editors. 1981. *Lexicon iconographicum mythologiae classicae (LIMC)*. Zürich & München: Artemis Verlag.

Anderson, C. 2006. *The long tail: how endless choice is creating unlimited demand*. London: Business Books.

Arafat, K. W. 1987. Iris or Nike? A divine libation scene on a missing lekythos. *BICS* 33:127-133.

—. 1990. *Classical Zeus: a study in art and literature*. Oxford: New York: Clarendon Press; Oxford University Press.

—. 1997. Review: The red and the black: studies in Greek pottery. *Classical Review* 47:393-394.

Arafat, K. W., and C. Morgan. 1989. Pots and potters in Athens and Corinth: a review. *Oxford Journal of Archaeology* 8:311-346.

Arnold, J. E., R. H. Colten, and S. Pletka. 1997. Contexts of cultural change in insular California. *American Antiquity* 62:300-318.

Austin, M. M., and P. Vidal-Naquet. 1977. *Economic and social history of Ancient Greece*. Berkely and Los Angeles, California: University of California Press.

Bak, P., C. Tang, and K. Wiesenfeld. 1987. Self-organized criticality: An explanation of the 1/f noise. *Physical Review Letters* 59:381.

Barabasi, A. L., and R. Albert. 1999. Emergence of scaling in random networks. *Science* 286:509-512.

Barringer, J. M. 1991. Europa and the Nereids: wedding or funeral? *American Journal of Archaeology* 95:657-667.

—. 1995. *Divine escorts: nereids in archaic and classical Greek art*. Ann Arbor: University of Michigan Press.

—. 2001. *The hunt in ancient Greece*. Baltimore, Md.; London: Johns Hopkins University Press.

Barron, J. P. 1972. New light on old walls: the murals of the Theseion. *The Journal of Hellenic Studies* 92:20-45.

Bass, F. M., T. V. Krishnan, and D. C. Jain. 1994. Why the Bass model fits without decision variables. *Marketing Science* 13:203-223.

Baum, W. M., P. J. Richerson, C. M. Efferson, and B. M. Paciotti. 2004. Cultural evolution in laboratory microsocieties including traditions of rule giving and rule following. *Evolution and Human Behavior* 25:305.

Baxandall, M. 1972. *Painting and experience in fifteenth century Italy*. Oxford: Clarendon Press.

Bažant, J. 1990. The case for a complex approach to Athenian vase painting. *Métis* 5:93-112.

Beazley, J. D. 1956. *Attic black-figure vase-painters*. Oxford: Clarendon Press.

—. 1963. *Attic red-figure vase-painters*, 2d ed. edition. Oxford: Clarendon Press.

—. 1971. *Paralipomena: additions to Attic black-figure vase-painters and to Attic red-figure vase-painters (second edition)*. Oxford: Clarendon Press.

—. 1986. *The development of Attic black-figure*, Rev. ed. edition. Berkeley: University of California Press.

Bentley, R. A. 2003. "An introduction to complex systems," in *Complex Systems and Archaeological Research*. Edited by R. A. Bentley and H. D. G. Maschner, pp. 9-26. Salt Lake City: University of Utah press.

Bentley, R. A., M. W. Hahn, and S. J. Shennan. 2004. Random drift and culture change. *Proceedings of the Royal Society of London Series B,* 271:1443-1450.

Bentley, R. A., M. W. Lake, and S. J. Shennan. 2005. Specialisation and wealth inequality in a model of a clustered economic network. *Journal of Archaeological Science* 32:1346-1356.

Bentley, R. A., C. P. Lipo, H. A. Herzog, and M. W. Hahn. 2007. Regular rates of popular culture change reflect random copying. *Evolution And Human Behavior* 28:151-158.

Bentley, R. A., and H. D. G. Maschner. 2000. A growing network of ideas. *Fractals* 3:227-237.

—. 2001. Stylistic change as a self-organized critical phenomenon: An archaeological study in complexity. *Journal Of Archaeological Method And Theory* 8:35-66.

Bentley, R. A., and S. J. Shennan. 2003. Cultural transmission and stochastic network growth. *American Antiquity* 68:459-485.

Bettinger, R. L. 1981. Sampling and Statistical Inference in Owens Valley. *American Antiquity* 46:656-660.

Bettinger, R. L., R. Boyd, and P. J. Richerson. 1996. "Style, Function, and Cultural Evolutionary Processes," in *Darwinian Archaeologies*. Edited by H. D. G. Maschner, pp. 133-164. New York: Plenum.

Bettinger, R. L., and J. Eerkens. 1999. Point typologies, cultural transmission, and the spread of bow-and-arrow technology in the prehistoric Great Basin. *American Antiquity* 64:231-242.

Bettinger, R. L., B. Winterhalder, and R. McElreath. 2006. A simple model of technological intensification. *Journal Of Archaeological Science* 33:538-545.

Bieber, M. 1949. Eros and Dionysos on Kerch vases. *Hesperia Supplements* 8:31-441.

Bikhchandani, S., D. Hirshleifer, and I. Welch. 1998. Learning from the behavior of others: conformity, fads, and informational cascades. *Journal Of Economic Perspectives* 12:151-170.

Boardman, J. 1975. *Athenian red figure vases: the archaic period: a handbook*. London: Thames and Hudson.

—. 1978. Exekias. *American Journal of Archaeology* 82:11-25.

—. 1979. The Athenian pottery trade: the classical period. *Expedition* 21:33-39.

—. 1982. Blood, wine or water? *Oxford Journal of Archaeology* 1:237-238.

—. 1983. The new Attic potter. *Oxford Journal of Archaeology* 2:247-248.

—. 1984. Centaurs and flying rocks. *Oxford Journal of Archaeology* 3:123-126.

—. 1988a. The trade figures. *Oxford Journal of Archaeology* 7:371-373.

—. 1988b. Trade in Greek decorated pottery. *Oxford Journal of Archaeology* 7:27-33.

—. 1991. "The sixth-century potters and painters of Athen and their public," in *Looking at Greek vases*. Edited by T. Rasmussen and N. Spivey, pp. 79-102. Cambridge: Cambridge University Press.

—. 1996. Review: crafty arts. *The Classical Review* 46:123-126.

—. 1996 (1964). *Greek art*. *World of Art*. London: Thames and Hudson.

—. 1998a. *Early Greek vase painting: 11th to 6th centuries BC: a handbook*. London: Thames & Hudson.

—. 1998b. "Herakles' monsters: indigenous or oriental?" in *Le bestiaire d'Héraclès: IIIe rencontre héracléenne: actes du Colloque organisé à l'Université de Liège et aux Facultés universitaires Notre-Dame de la Paix de Namur, du 14 au 16 novembre 1996*, vol. Supplement 7, *Kernos*. Edited by C. Bonnet, C. Jourdain-Annequin, and V. Pirenne-Delforge, pp. 27-35. Liège: Centre international d'étude de la religion grecque antique.

—. 2001. *The history of Greek vases: potters, painters, and pictures*. London: Thames & Hudson.

—. 2003. 'Reading' Greek vases? *Oxford Journal of Archaeology* 22:109-114.

Bodley, J. H. 1999. Socioeconomic growth, culture scale, and household well-being: a test of the power-elite hypothesis. *Current Anthropology* 40:595-620.

Boegehold, A. L. 1983. A new Attic black figure potter. *American Journal of Archaeology* 87:89-90.

Bonfante, L. 1989. Nudity as a costume in Classical art. *American Journal of Archaeology* 93:543-570.

Bonnet, C., C. Jourdain-Annequin, and V. Pirenne-Delforge. Editors. 1998. *Le bestiaire d'Héraclès: IIIe rencontre héracléenne: actes du Colloque organisé à l'Université de Liège et aux Facultés universitaires Notre-Dame de la Paix de Namur, du 14 au 16 novembre 1996*. Vol. Supplement 7. *Kernos*. Liège: Centre international d'étude de la religion grecque antique.

Boulter, C. G. 1981. The study of Greek vases. *American Journal of Archaeology* 85:105-106.

Bouzek, J. A. N. 1994. The distribution of Greek painted pottery in the Mediterranean and in the Black Sea region: a comparison. *Oxford Journal of Archaeology* 13:241-243.

Boyd, R., and P. J. Richerson. 1985. *Culture and the evolutionary process*. Chicago: The University of Chicago Press.

—. 2005. *The origin and evolution of cultures*. Oxford; New York: Oxford University Press.

Brantingham, P. J. 2007. A unified evolutionary model of archaeological style and function based on the price equation. *American Antiquity* 72:395-416.

Brommer, F. 1973. *Vasenlisten zur griechischen Heldensage*. Marburg: N. G. Elwert.

Burns, J. 1981. Boreas and Oreithyia in Greek vase painting. *ZAnt* 31:215-232.

Cabrera, P. 1998. Greek trade in Iberia: the extent of interaction. *Oxford Journal of Archaeology* 17:191-206.

Cameron, C. M. 1990. Avant-gardism as a mode of culture change. *Cultural Anthropology* 5:217-230.

Carpenter, T. H. 1983. On the dating if the Tyrrhenian group. *Oxford Journal of Archaeology* 2:279-293.

—. 1997. *Dionysian imagery in fifth-century Athens*. Oxford: Clarendon Press.

Carpenter, T. H., and C. A. Faraone. Editors. 1993. *Masks of Dionysus*. Ithaca; London: Cornell University Press.

Casson, L. 1979. Traders and trading: Classical Athens. *Expedition* 21:25-32.

Cavalier, K. 1995. Did not potters portray Peisistratos posthumously as Herakles? *Electronic Antiquity* 2:5:http://scholar.lib.vt.edu/ejournals/ElAnt/V2N5/cavalier.html.

Chippindale, C., and D. W. J. Gill. 2000. Material consequences of contemporary classical collecting. *American Journal Of Archaeology* 104:463-511.

Cohen, B. 1991. The literate potter: a tradition of incised signatures on Attic vases. *Metropolitan Museum Journal* 26:49-95.

—. 2006. *The colors of clay: special techniques in Athenian vases*. Los Angeles: J. Paul Getty Museum.

Collard, M., S. J. Shennan, and J. J. Tehrani. 2006. Branching, blending, and the evolution of cultural similarities and differences among human populations. *Evolution And Human Behavior* 27:169-184.

Cook, B. F. 1989a. Footwork in Ancient Greek swordsmanship. *Metropolitan Museum Journal* 24:57-64.

Cook, R. M. 1989b. The Francis-Vickers chronology. *The Journal of Hellenic Studies* 109:164-170.

—. 1997. *Greek painted pottery, 3rd edition*. London and New York: Routledge.

Corbett, P. E. 1949. Attic pottery of the later fifth century from the Athenian agora. *Hesperia* 18:298-351.

—. 1965. Preliminary sketch in Greek vase-painting. *The Journal of Hellenic Studies* 85:16-28.

Crow, J. F., and M. Kimura. 1970. *An introduction to population genetics theory*. New York: Harper & Row.

Cuno, J. Editor. 2004. *Whose Muse? Art Museums and the Public Trust*. Princeton: Princeton University Press.

Curry, M. 1991. Review: Locri Epizephyrii and the vase trade. *The Classical Review* 41:446-447.

Darwin, C. 1871. *The descent of man, and selection in relation to sex*. London: John Murray (reprinted 2003 by Gibson Square Books).

David, N., J. Sterner, and K. Gavua. 1988. Why pots are decorated. *Current Anthropology* 29:365-389.

Dawkins, R. 1976. *The selfish gene*. Oxford: Oxford University Press.

De Angelis, F. 2006. Going against the grain in Sicilian Greek economics. *Greece & Rome* 53:29-47.

Dearden, C. 1999. Plays for export. *Phoenix* 53:222-248.

Dee, J. H. 2002. The first downloadable word-frequency database for classical and medieval Latin. *Classical Journal* 98:59-67.

Dissanayake, E. 1988. *What is art for?* Seattle and London: University of Washington Press.

—. 1992. *Homo aestheticus: where art comes from and why*. New York: The Free Press.

Dodds, P. S., and D. J. Watts. 2005. A generalized model of social and biological contagion. *Journal Of Theoretical Biology* 232:587-604.

Dunnell, R. C. 1978. Style and function: a fundamental dichotomy. *American Antiquity* 43:192-202.

—. 1980. "Evolutionary Theory and Archaeology," in *Advances in archaeological method and theory*, vol. 3. Edited by M. B. Schiffer, pp. 35-99. New York: Academic Press.

—. 1989. "Aspects of the application of evolutionary theory in archaeology," in *Archaeological thought in America*. Edited by C. Lamberg-Karlovsky, pp. 35-49. New York: Cambridge University Press.

Dunnell, R. C., and D. M. Greenlee. 1999. Late woodland period "waste" reduction in the Ohio river valley. *Journal of Anthropological Archaeology,* 18:376-395.

Edwards, M. W. 1960. Representation of Maenads on Archaic red-figure vases. *The Journal of Hellenic Studies* 80:78-87.

Eerkens, J. W., and C. P. Lipo. 2005. Cultural transmission, copying errors, and the generation of variation in material culture and the archaeological record. *Journal Of Anthropological Archaeology* 24:316-334.

—. 2007. Cultural transmission theory and the archaeological record: providing context to understanding variation and temporal changes in material culture. *Journal Of Archaeological Research* 15:239-274.

Eisman, M., M. 1973. How a Greek artist once painted himself into a corner. *Expedition* 15:28-30.

Eisman, M. M., and L. Turnbull. 1978. Robinson's kiln skyphos. *American Journal of Archaeology* 82:394-399.

Eitner, L. E. A. 1971. *Neoclassicism and Romanticism 1750-1850: sources and documents*. Englewood Cliffs, NJ: Prentice Hall.

Evershed, R. P., S. N. Dudd, V. R. Anderson-Stojanovic, and E. R. Gebhard. 2003. New chemical evidence for the use of combed ware pottery vessels as beehives in Ancient Greece. *Journal of Archaeological Science* 30:1-12.

Ewens, W. J. 1972. Sampling theory of selectively neutral alleles. *Theoretical Population Biology* 3:87-112.

Fillieres, D., G. Harbottle, and E. V. Sayre. 1983. Neutron-activation study of figurines, pottery, and workshop materials from the Athenian agora, Greece. *Journal of Field Archaeology* 10:55-69.

Finley, M. I. 1981. *Economy and society in ancient Greece*. London: Chatto & Windus.

Fisher, R. 1958. *The genetical theory of natural selection. 2nd edition*. New York: Dover.

Fitzhugh, B. 2001. Risk and invention in human technological evolution. *Journal of Anthropological Archaeology,* 20:125-167.

Gablik, S. 1976. *Progress in art*. London: Thames & Hudson.

Garland, R. 1998. *Daily life of the ancient Greeks*. Westport, Conn.; London: Greenwood Press.

Gartman, D. 2002. Bourdieu's theory of cultural change: explication, application, critique. *Sociological Theory* 20:255-277.

Gaunt, J. 1995. A cup in Princeton. *Record of the Art Museum, Princeton University* 54:31-38.

Geddes, A. G. 1987. Rags and riches: the costume of Athenian men in the fifth century. *The Classical Quarterly* 37:307-331.

Gell, A. 1998. *Art and agency: an anthropological theory*. Oxford: Clarendon Press.

Gill, D. W. J. 1988a. Expressions of wealth - Greek art and society. *Antiquity* 62:735-743.

—. 1988b. 'Trade in Greek decorated pottery': some corrections. *Oxford Journal of Archaeology* 7:369-370.

—. 1991. Pots and trade: spacefillers or objets d'art? *The Journal of Hellenic Studies* 111:29-47.

Gillespie, J. H. 1977. Sampling theory for alleles in a random environment. *Nature* 266:443-445.

Giudice, F. 1979. Osservazioni sul commercio dei vasi attica in Etruria e in Sicilia: su una lekythos del pittore della Gigantomachia con l'iscrizione "LASASA". *Cronache* 18:153-162.

Gladwell, M. 2001. *The tipping point: how little things can make a big difference*. London: Abacus.

Glynn, R. 1983. "The Beazley archive computer project," in *Image et céramique grecque: actes du colloque de Rouen, 25-26 novembre 1982*. Edited by F. Lissarrague and F. Thelamon, pp. 67-79. Rouen: Université de Rouen.

Gohr, S. Editor. 1986. *Museum Ludwig Köln; Gemälde, Skulpturen, Environments vom Expressionismus bis zur Gegenwart*. Munich: Prestel-Verlag.

Goldber, E. L. 1988. *After Vasari: history, art and patronage in late Medici Florence*. Princeton: Princeton University Press.

Golden, M., and P. Toohey. Editors. 1997. *Inventing ancient culture: historicism, periodization, and the ancient world*. London; New York: Routledge.

Gombrich, E. H. 1972. *The story of art, 13th edition*. Oxford: Phaidon.

—. 2002 (1959). *Art & illusion: a study in the psychology of pictorial representation*. London & New York: Phaidon.

Goossens, E., and S. Thielemans. 1996. The popularity of painting sport scenes on Attic black and red figure vases: a CVA-based research with a statistical note by O. Thas. *Bulletin Antieke Beschaving* 71:59-94.

Grayson, D. K. 1970. Statistical Inference and Northeastern Adena. *American Antiquity* 35:102-104.

Hahn, M. W., and R. A. Bentley. 2003. Drift as a mechanism for cultural change: an example from baby names. *Proceedings: Biological Sciences* 270:S120-S123.

Hall, M. C. 1981. Land-Use Changes in Owens Valley Prehistory: A Matter of Statistical Inference. *American Antiquity* 46:648-656.

Hammond, N. G. L., and W. G. Moon. 1978. Illustrations of early tragedy at Athens. *American Journal of Archaeology* 82:371-383.

Hannah, R. 1995. Peisistratos, the Peisistratids and the introduction of Herakles to Olympos: an alternative scenario. *Electronic Antiquity* 3:2:http://scholar.lib.vt.edu/ejournals/ElAnt/V3N2/hannah.html.

Hannestad, L. 1987. "The Athenian potter and the home market," in *Symposium on Ancient Greek and Related Pottery (3rd: 1987: Copenhagen, Denmark)*. Edited by J. Christiansen and T. Melander, pp. 222-229. Copenhagen: Nationalmuseet: Ny Carlsberg Glyptotek: Thorvaldsens Museum.

—. 1991. "Athenian pottery in Italy c. 550-470: Beazley and quantitative studies," in *I vasi attici ed altre ceramiche coeve in Sicilia*, vol. II, *Cronache di archeologia 30*, pp. 211-216. Catania: Consiglio nazionale delle ricerche, Centro di studio sull'archeologia greca.

Hansson, M. C., and B. P. Foley. 2008. Ancient DNA fragments inside Classical Greek amphoras reveal cargo of 2400-year-old shipwreck. *Journal of Archaeological Science* 35:1169-1176.

Harbottle, G., M. J. Hughes, and S. Seleem. 2005. The origin of black-figure Greek ceramics found in Naucratis (Nile Delta). *Archaeometry* 47:511-518.

Harrison, E. B. 1972. Preparations for Marathon, the Niobid painter and Herodotus. *The Art Bulletin* 54:390-402.

Hawkins, J. A., C. E. Hughes, and R. W. Scotland. 1997. Primary homology assessment, characters and character states. *Cladistics-The International Journal Of The Willi Hennig Society* 13:275-283.

Hedreen, G. 1994. Silens, nymphs, and maenads. *The Journal of Hellenic Studies* 114:47-69.

—. 2004. The return of Hephaistos, Dionysiac processional ritual and the creation of a visual narrative. *The Journal of Hellenic Studies* 124:38-64.

—. 2006. "I let go my force just touching her hair": male sexuality in Athenian vase, paintings of silens and iambic poetry. *Classical Antiquity* 25:277-U19.

Heilmeyer, W. D. 1988. Ancient-art and artistic production: the study of the workshops in Classical archaeology. *Quaderni Urbinati Di Cultura Classica*:7-&.

Hemelrijk, J. M. 1991. "A closer look at the potter," in *Looking at Greek vases*. Edited by T. Rasmussen and N. Spivey, pp. 233-256. Cambridge: Cambridge University Press.

Henle, J. E. 1973. *Greek myths: a vase painter's notebook*. Bloomington; London: Indiana University Press.

Henrich, J. 2001. Cultural transmission and the diffusion of innovations: adoption dynamics indicate that biased cultural transmission is the predominate force in behavioral change and much of sociocultural evolution. *American Anthropologist* 103:992-1013.

Henrich, J., and R. Boyd. 2002. Culture and cognition: why cultural evolution does not require replication of representations. *Culture and Cognition,* 2:87-112.

Henrich, J., and F. J. Gil-White. 2001. The evolution of prestige: freely conferred deference as a mechanism for enhancing the benefits of cultural transmission. *Evolution and Human Behavior* 22:165-196.

Herzog, H. A., R. A. Bentley, and M. W. Hahn. 2004. Random drift and large shifts in popularity of dog breeds. *Proceedings: Biological Sciences* 271:S353-S356.

Hill, D. K. 1947. The technique of Greek metal vases and its bearing on vase forms in metal and pottery. *American Journal of Archaeology* 51:248-256.

Hoffmann, H. 1979. In the wake of Beazley: prolegomena to an anthropological study of Greek vase-painting. *Hephaistos* I:61-70.

—. 1984. Charos, Charun, Charon. *Oxford Journal of Archaeology* 3:65-69.

Hollingsworth, M. 1996. *Patronage in sixteenth century Italy*. London: John Murray.

Holly, M. A. 1984. *Panofsky and the foundations of art history.* Ithaca & London: Cornell University Press.

Holmberg, E., J. 1989. Who made the vases of the Red-line Painter and relations. *ORom* 17:61-76.

Houston, G. W. 2003. Academe's Aeneas syndrome: Where in the world are we headed. *Classical Journal* 98:281-287.

Humphreys, S. C. 1978. Artists' mistakes. *International Journal of Nautical Archaeology* 7:78-87.

Hurwit, J. M. 2002. Reading the Chigi vase. *Hesperia* 71:1-22.

Irwin, D. 1972. *Winckelmann; writings on art*. London: Phaidon.

Johnston, A. 1991. "Greek vases in the marketplace," in *Looking at Greek vases*. Edited by T. Rasmussen and N. Spivey, pp. 203-232. Cambridge: Cambridge University Press.

Johnston, A. W. 1974. Trademarks on Greek vases. *Greece & Rome* 21:138-152.

—. 1978. Lists of contents: Attic vases. *American Journal of Archaeology* 82:222-226.

Jones, A. H. M. 1955. The social structure of Athens in the fourth century. *The Economic History Review* 8:141-155.

Karlin, S., and J. McGregor. 1972. Sampling theory of selectively neutral alleles. *Theoretical Population Biology* 3:113-116.

Katz, E., and P. F. Lazarsfeld. 1955. *Personal Influence; the Part Played by People in the Flow of Mass Communications*. Glencoe, IL: Free Press.

Keay, S., and S. Moser. Editors. 2004. *Greek art in view: essays in honour of Brian Sparkes*. Oxford: Oxbow.

Keenleyside, A., H. Schwarcz, and K. Panayotova. 2006. Stable isotopic evidence of diet in a Greek colonial population from the Black Sea. *Journal of Archaeological Science* 33:1205-1215.

Keesling, C. M. 2005. Patrons of Athenian votive monuments of the Archaic and Classical periods: three studies. *Hesperia* 74:395-426.

Kilinski, K., II. 1978. The Boeotian dancers group. *American Journal of Archaeology* 82:173-191.

Kilmer, M. F., and R. Develin. 2001. Sophilos' vase inscriptions and cultural literacy in archaic Athens. *Phoenix-The Journal Of The Classical Association Of Canada* 55:9-43.

Kimura, M., and J. F. Crow. 1964. Number of alleles that can be maintained in finite population. *Genetics* 49:725-738.

Kirkpatrick, J., Timothy, and F. Dunn, M. 2002. Heracles, Cercopes, and paracomedy. *Transactions of the American Philological Association* 132:29-61.

Knapp, A. B. 2000. Archaeology, science-based archaeology and the mediterranean bronze age metals trade. *European Journal of Archaeology* 3:31-56.

Kohler, T. A., S. VanBuskirk, and S. Ruscavage-Barz. 2004. Vessels and villages: evidence for conformist transmission in early village aggregations on the Pajarito Plateau, New Mexico. *Journal Of Anthropological Archaeology* 23:100-118.

Kron, G. 2005. Anthropometry, physical anthropology, and the reconstruction of ancient health, nutrition, and living standards. *Historia* 54:68-83.

Kuleff, I., T. Stoyanov, and E. Pernicka. 2007. On the origin of stamped amphorae from Thrace (Bulgaria). *Oxford Journal of Archaeology* 26:53-78.

Kurtz, D. C. 1975. *Athenian white lekythoi: patterns and painters*. Oxford: Clarendon Press.

—. 1983. Gorgos' cup: an essay in connoisseurship. *The Journal of Hellenic Studies* 103:68-86.

Langin-Hooper, S. M. 2007. Social networks and cross-cultural interaction: a new interpretation of the female terracotta figurines of Hellenistic Babylon. *Oxford Journal of Archaeology* 26:145-165.

Lawall, M. L. 2002. Graffiti, wine selling, and the reuse of amphoras in the Athenian agora, ca.430 to 400 BC (vol 69.1, pg. 35 and pg. 59, 2000). *Hesperia* 71:3-90.

Layton, R. 1991. *The anthropology of art*. Cambridge: Cambridge University Press.

Leventi, I. 2007. The Mondragone relief revisited: Eleusinian cult iconography in Campania. *Hesperia* 76:107-141.

Lipo, C. P., M. E. Madsen, R. C. Dunnell, and T. Hunt. 1997. Population structure, cultural transmission, and frequency seriation. *Journal Of Anthropological Archaeology* 16:301-333.

Lissarrague, F. 1990. *The aesthetics of the Greek banquet: images of wine and ritual*. Princeton, N.J.: Princeton University Press.

Lowenstam, S. 1992. The uses of vase-depictions in Homeric studies. *Transactions of the American Philological Association (1974-)* 122:165-198.

—. 1997. Talking vases: the relationship between the Homeric poems and Archaic representations of epic myth. *Transactions of the American Philological Association (1974-)* 127:21-76.

Lundgreen, B. 1997. A methodological enquiry: the great bronze Athena by Pheidias. *Journal Of Hellenic Studies* 117:190-197.

Lynch, K. M., and J. K. Papadopoulos. 2006. A study of the potty in Archaic and Classical Athens. *Hesperia* 75:1-32.

Lyons, C. L. 2007. Nola and the historiography of Greek vases. *Journal of the History of Collections* 19:239-247.

MacDonald, B. R. 1981. The emigration of potters from Athens in the late fifth century B. C. and its effect on the Attic pottery industry. *American Journal of Archaeology* 85:159-168.

—. 1982. The import of Attic pottery to Corinth and the question of trade during the Peloponnesian war. *The Journal of Hellenic Studies* 102:113-123.

Mace, R., and C. J. Holden. 2005. A phylogenetic approach to cultural evolution. *Trends In Ecology & Evolution* 20:116-121.

MacGregor, N. 2004. "A Pentecost in Trafalger Square," in *Whose Muse? Art Museums and the Public Trust*. Edited by J. Cuno, pp. 27-48. Princeton: Princeton University Press.

Marconi, C. Editor. 2004a. *Greek vases: images, contexts, and controversies; proceedings of the conference sponsored by the Center for the Ancient Mediterranean at Columbia University, 23-24 March 2002*. Leiden: Boston: Brill.

—. 2004b. "Images for a warrior: on a group of Athenian vases and their public," in *Greek vases: images, contexts, and controversies; proceedings of the conference sponsored by the Center for the Ancient Mediterranean at Columbia University, 23-24 March 2002*. Edited by C. Marconi, pp. 27-40. Leiden: Boston: Brill.

Marini, M. 2004. Cultural evolution and economic growth: a theoretical hypothesis with some empirical evidence. *The Journal of Socio-Economics* 33:765-784.

Maschner, H. D. G. Editor. 1996. *Darwinian Archaeologies*. New York: Plenum.

Matheson, S., B. 1994. The mission of Triptolemus and the politics of Athens. *Greek, Roman and Byzantine Studies* 35:345-372.

Mattusch, C. C. 1980. The Berlin Foundry cup: the casting of Greek bronze statuary in the early fifth century B. C. *American Journal of Archaeology* 84:435-444.

Maxmin, J. 1974. Euphronios 'Epoiesen': portrait of the artist as a presbyopic potter. *Greece & Rome* 21:178-180.

Mayor, A. 2000. The 'Monster of Troy' vase: the earliest artistic record of a vertbrate fossil discovery? *Oxford Journal of Archaeology* 19:57-63.

McElreath, R., M. Lubell, P. J. Richerson, T. M. Waring, W. Baum, E. Edsten, C. Efferson, and B. Paciotti. 2005. Applying evolutionary models to the laboratory study of social learning. *Evolution And Human Behavior* 26:483-508.

McGrail, S. 1989. The shipment of traded goods and of ballast in antiquity. *Oxford Journal of Archaeology* 8:353-358.

McPhee, I. A. N. 1991. A Corinthian red-figured calyx-krater and the Domrena painter. *Oxford Journal of Archaeology* 10:325-334.

Mertens, J. R. 1972. A white-ground cup by Euphronios. *Harvard Studies in Classical Philology* 76:271-281.

—. 1974. Attic white-ground cups: a special class of vases. *Metropolitan Museum Journal* 9:91-108.

Merton, R. K. 1968. The Role-Set:Problems in Sociological Theory. *British Journal of Sociology* 8:106-120.

Miles, M. M. 1998. The City Eleusinion. *The Athenian Agora* 31:iii-233.

Miller, G. 1999a. "Sexual selection for cultural displays," in *The Evolution of Culture*. Edited by C. K. a. C. P. Robin Dunbar, pp. 71-91. Edinburgh: Edinburgh University Press.

—. 2000. *The mating mind*. London: Vintage.

Miller, M. C. 1997. *Athens and Persia in the fifth century B.C.* Cambridge: Cambridge University Press.

—. 1999b. Reexamining transvestism in Archaic and Classical Athens: the Zewadski stamnos. *American Journal of Archaeology* 103:223-253.

Miller, S. G. 1986. Eros and the arms of Achilles. *American Journal of Archaeology* 90:159-170.

Mirti, P. 2000. X-ray microanalysis discloses the secrets of ancient Greek and Roman potters. *X-Ray Spectrometry* 29:63-72.

—. 2004. Technology of production of red figure pottery from Attic and southern Italian workshops. *Analytical and bioanalytical chemistry* 380: 712-718.

Mitchell, A., G. 2004. Humour in Greek vase-painting. *Revue archeologique* 1:3-32.

Mithen, S. 1999. "Symbolism and the supernatural," in *The Evolution of Culture*. Edited by C. K. a. C. P. Robin Dunbar, pp. 147-169. Edinburgh: Edinburgh University Press.

Moore, G. 1991. *Crossing the Chasm*. New York: Harper Collins.

Moore, M. B. 1975. Attic black figure from Samothrace. *Hesperia* 44:234-250.

—. 1980. Exekias and Telamonian Ajax. *American Journal of Archaeology* 84:417-434.

—. 1997. Attic red-figured and white-ground pottery. *The Athenian Agora* 30:iii-419.

—. 2003. The Passas painter: a Protoattic "realist"? *Metropolitan Museum Journal* 38:15-7.

Mueller, U., and A. Mazur. 2001. Evidence of unconstrained directional selection for male tallness. *Behavioural Ecology and Sociobiology* 50:302-311.

Mulder, M. B., C. L. Nunn, and M. C. Towner. 2006. Cultural macroevolution and the transmission of traits. *Evolutionary Anthropology* 15:52-64.

Neer, R. T. 1995. The lion's eye: imitation and uncertainty in Attic red-figure. *Representations*:118-153.

—. 1998. Imitation, inscription, antilogic. *Métis* 13:17-38.

—. 2002. *Style and politics in Athenian vase-painting: the craft of democracy, ca. 530-460 B.C.E.* Cambridge: Cambridge University Press.

—. 2004. The Athenian treasury at Delphi and the material of politics (Classical antiquity, ancient Greek architecture). *Classical Antiquity* 23:63-94.

Neiman, F. 1995. Stylistic variation in evolutionary perspective: inferences from decorative diversity and interassemblage distance in Illinois woodland ceramic assemblages. *American Antiquity* 60:7-36.

Newman, M. E. J. 2005. Power laws, Pareto distributions and Zipf's law. *Contemporary Physics* 46:323-351.

Nilsson, A. 1999. The function and reception of Attic figured pottery Spina, a case study. *ARID* 26:7-23.

Noble, J. V. 1960. The technique of Attic vase-painting. *American Journal of Archaeology* 64:307-318.

—. 1985. Refiring Greek vases. *American Journal of Archaeology* 89:515-516.

Nunn, C. L., M. B. Mulder, and S. Langley. 2006. Comparative methods for studying cultural trait evolution: a simulation study. *Cross-Cultural Research* 40:177-209.

O'Brien, M. J., J. Darwent, and R. L. Lyman. 2001. Cladistics is useful for reconstructing archaeological phylogenies: Palaeoindian points from the Southeastern United States. *Journal Of Archaeological Science* 28:1115-1136.

O'Brien, M. J., and R. L. Lyman. 2000. Darwinian evolutionism is applicable to historical archaeology. *International Journal of Historical Archaeology* 4:71-112.

—. 2002. Evolutionary archeology: current status and future prospects. *Evolutionary Anthropology* 11:26-36.

O'Brien, M. J., R. L. Lyman, Y. Saab, E. Saab, J. Darwent, and D. S. Glover. 2002. Two issues in archaeological phylogenetics: taxon construction and outgroup selection. *Journal Of Theoretical Biology* 215:133-150.

Oakley, J. H. 1982. Danae and Perseus on Seriphos. *American Journal of Archaeology* 86:111-115.

—. 1988a. Attic red-figured skyphoi of Corinthian shape. *Hesperia* 57:165-191.

—. 1988b. Perseus, the Graiai, and Aeschylus' Phorkides. *American Journal of Archaeology* 92:383-391.

—. 1995. "Nuptial nuances: wedding images in non-wedding scenes of myth," in *Pandora: women in classical Greece*. Edited by E. D. Reeder, pp. 63-73. Baltimore: Princeton: Walters Art Gallery; Princeton University Press.

—. 1998. Why study a Greek vase-painter? a response to Whitley's Beazley as theorist. *Antiquity* 72:209-213.

—. 2007. The departure of the Argonauts on the Dinos painter's bell krater in Gela. *Hesperia* 76:347-357.

Ober, J., W. Scheidel, B. D. Shaw, and D. Sanclemente. 2007. Toward open access in ancient studies: The Princeton-Stanford working papers in Classics. *Hesperia* 76:229-242.

Odlyzko, A. M. 1995. Tragic loss or good riddance? The impending demise of traditional scholarly journals. *Notices of the American Mathematical Society* 42:49-53.

Olin, M. 1992. *Forms of representation in Alois Riegl's theory of art*. University Park, Pennsylvania: Pennsylvania University Press.

Onians, J. 1991. Idea and product: potter and philosopher in Classical Athens. *Journal of Design History* 4:65-73.

Osborne, R. 1983. The myth of propaganda and the propaganda of myth. *Hephaistos* 5:61-70.

—. 1991. The potential mobility of human populations. *Oxford Journal of Archaeology* 10:231-252.

—. 1993. Women and sacrifice in Classical Greece. *The Classical Quarterly* 43:392-405.

—. 1996a. *Greece in the making, 1200-479 BC*. London: Routledge.

—. 1996b. Pots, trade and the archaic Greek economy. *Antiquity* 70:31-44.

—. 1997. Law, the democratic citizen and the representation of women in Classical Athens. *Past and Present*:3-33.

—. 1999. Archaeology and the Athenian Empire. *Transactions of the American Philological Association* 129:319-332.

—. 2001. Why did Athenian pots appeal to the Etruscans? *World Archaeology* 33:277-295.

—. 2004a. Hoards, votives, offerings: the archaeology of the dedicated object. *World Archaeology* 36:1-10.

—. 2004b. "Images of a warrior: On a group of Athenian vases and their public," in *Greek vases: images, contexts, and controversies; proceedings of the conference sponsored by the Center for the Ancient Mediterranean at Columbia University, 23-24 March 2002*. Edited by C. Marconi, pp. 41-54. Leiden: Boston: Brill.

—. 2004c. "Workships and the iconography and distribution of Athenian red-figure pottery: a case study," in *Greek art in view: essays in honour of Brian Sparkes*. Edited by S. Keay and S. Moser, pp. 78-94. Oxford: Oxbow.

—. 2007. What travelled with Greek pottery? *Mediterranean Historical Review* 22:85.

Paleothodoros, D. 2002. Why did the Etruscans buy Attic vases? *Les études classiques* 70:139-160.

—. 2007. Commercial Networks in the Mediterranean and the Diffusion of Early Attic Red-figure Pottery (525-490 BCE). *Mediterranean Historical Review* 22:165 - 182.

Panitch, J. M., and S. Michalak. 2005. The serials crisis; A White Paper for the UNC-Chapel Hill Scholarly Communications Convocation.http://www.unc.edu/scholcomdig/whitepapers/panitch-michalak.html.

Panofsky, E. 1955. *Meaning in the visual arts*. London: Penguin.

Parsons, P. A. 1964. Parent age and the offspring. *The Quarterly Review of Biology* 39:258-275.

Patterson, C. 2006. 'Citizen cemeteries' in classical Athens? *Classical Quarterly* 56:48-56.

Peirce, S. 1998. Visual language and concepts of cult on the "Lenaia vases". *Classical antiquity* 17: 59-95.

Pemberton, E. G. 1978. Vase painting in ancient Corinth. *Archaeology* 31:27-33.

—. 1998. Between art history and archaeology: recent studies in Greek ceramics. *American Journal of Archaeology* 102:424-428.

Penny, N. 1993. *The materials of sculpture*. New Haven: Yale University Press.

Perry, S. E. 2006. What cultural primatology can tell anthropologists about the evolution of culture. *Annual Review Of Anthropology* 35:171-190.

Pinney, G. F. 1981. The nonage of the Berlin painter. *American Journal of Archaeology* 85:145-158.

Pinney, G. F., and B. S. Ridgway. 1981. Herakles at the ends of the earth. *The Journal of Hellenic Studies* 101:141-144.

Power, C. 1999. "'Beauty magic': the origins of art," in *The Evolution of Culture*. Edited by C. K. a. C. P. Robin Dunbar, pp. 92-112. Edinburgh: Edinburgh University Press.

Preziosi, D. 1989. *Rethinking art history: meditations on a coy science*. New Haven & London: Yale University Press.

Pritchard, D., M. 1999. Fool's gold and silver: reflections on the evidentiary status of finely painted Attic pottery. *Antichthon* 33:1-27.

Rands, R. L. 1961. Elaboration and invention in ceramic traditions. *American Antiquity* 26:331-340.

Rasmussen, T., and N. Spivey. Editors. 1991. *Looking at Greek vases*. Cambridge: Cambridge University Press.

Reilly, J. 1989. Many brides: "mistress and maid" on Athenian lekythoi. *Hesperia* 58:411-444.

Rhodes, P. J. 2003. Nothing to do with democracy: Athenian drama and the polis. *The Journal of Hellenic Studies* 123:104-119.

—. 2006. *A history of the classical Greek world: 478-323 B.C.* Oxford: Blackwell.

Richlin, A. 2004. Forty-eight years of classical scholarship. *The Classical Review* 54:12-17.

Richter, G. M. A. 1987. *A handbook of Greek art*, 9th ed. edition. London; New York: Phaidon.

Richter, G. M. A., and M. J. Milne. 1935. *Shapes and names of Athenian vases*. New York: Plantin Press.

Ridgway, B. S. 1986. The state of research on ancient art. *The Art Bulletin* 68:7-23.

Ridley, M. 1983. *The explanation of organic diversity: the comparitive method and adaptations for mating*. Oxford: Clarendon.

Roaf, M., and J. Boardman. 1980. A Greek painting at Persepolis. *The Journal of Hellenic Studies* 100:204-206.

Roberts, S. R. 1973. Evidence for a pattern in Attic pottery production Ca 430-350 BC. *American Journal Of Archaeology* 77:435-437.

Robertson, C. M. 1977. The Beazley Archive. *The Journal of Hellenic Studies* 97:v.

Robertson, C. M., and M. Beard. 1991. "Adopting an approach," in *Looking at Greek vases*. Edited by T. Rasmussen and N. Spivey, pp. 1-36. Cambridge: Cambridge University Press.

Robertson, M. 1965. Attic red-figure vase-painters. *The Journal of Hellenic Studies* 85:90-101.

—. 1992. *The art of vase-painting in classical Athens*. Cambridge: Cambridge University Press.

Rosait, R., L. Quartili, and G. M.P. 1989. *La ceramica attica nell' Mediterraneo: analisi computerizzata delle diffusione: Le fase initiali 630-560 a.c.* Bologna: Co-operative Libraria Universitaria Editrice Bologna.

Rosenberg, M. 1990. The mother of invention: evolutionary theory, territoriality and the origins of agriculture. *American Anthropologist* 92:399 - 415.

—. 1994. Pattern, process and hierarchy in the evolution of culture. *Journal Of Anthropological Archaeology* 13:307-340.

Rosenmeyer, T. G. 1951. Eros: Erotes. *Phoenix* 5:11-22.

Rosivach, V. J. 2005. How safe was travel abroad? Some evidence from Athenian vases. *Historia* 54:343.

Rouet, P. 2001. *Approaches to the study of Attic vases: Beazley and Pottier*. Oxford: Oxford University Press.

Rusten, J. 2006. Who "invented" comedy? The ancient candidates for the origins of comedy and the visual evidence. *American Journal Of Philology* 127:37-66.

Salmon, J. 1999. The economic role of the Greek city. *Greece & Rome* 46:147-167.

Sams, G. K. 1979. Imports at Gordion; Lydian and Persian periods. *Expedition* 21:6-17.

Scanlon, T. F. 2005. The dispersion of pederasty and the athletic revolution in sixth-century BC Greece. *Journal Of Homosexuality* 49:63-85.

Schapiro, M. 1951. "Style," in *Anthropology Today*. Edited by A. Kroeber, pp. 287-312. Chicago: University of Chicago Press.

Schaus, G., P. 1988. The beginning of Greek polychrome painting. *The Journal of Hellenic Studies* 108:107-117.

Scheidel, W. 2003. The Greek demographic expansion: models and comparisons. *The Journal of Hellenic Studies* 123:120-140.

Scheps, S. 1982. Statistical Blight. *American Antiquity* 47:836-851.

Seeberg, A. 1994. Epoiesen, Egrapsen, and the organization of the vase trade. *The Journal of Hellenic Studies* 114:162-164.

Sen, A. 1981. *Poverty and famines: an essay on entitlement and deprivation*. Oxford: Clarendon Press.

Shapiro, H. A. 1981. Courtship scenes in Attic vase-painting. *American Journal of Archaeology* 85:133-143.

—. 1990. Old and new heroes, narrative, composition, and subject in Attic black-figure. *Classical Antiquity* 9:114-148.

—. 1991a. The iconography of mourning in Athenian art. *American Journal of Archaeology* 95:629-656.

—. 1991b. "Theseus: aspects of the hero in Archaic Greece," in *New perspectives in early Greek art*. Edited by D. Buitron-Oliver, pp. 123-139. Washington, D.C.: National Gallery of Art.

—. 1994. *Myth into art: poet and painter in classical Greece*. London; New York: Routledge.

Shear, T. L. 1993. The Persian destruction of Athens: evidence from agora deposits. *Hesperia* 62:383-482.

Shennan, S. J. 1997. *Quantifying archaeology*. Edinburgh: Edinburgh University Press.

—. 2002. *Genes, memes and human history*. London: Thames & Hudson.

Shennan, S. J., and J. R. Wilkinson. 2001. Ceramic style change and neutral evolution: a case study from Neolithic Europe. *American Antiquity* 66:577-593.

Shiner, L. 2001. *The invention of art: a cultural history*. Chicago & London: The University of Chicago Press.

Shirky, C. 2008. *Here Comes Everybody: The Power of Organizing without Organizations*. London: Allen Lane.

Silver, M. 2006. Slaves versus free hired workers in Ancient Greece. *Historia* 55:257-263.

Simkin, M. V., and V. P. Roychowdhury. 2006. Theory of aces: fame by chance or merit? *Journal Of Mathematical Sociology* 30:33-42.

Skelton, C. 2008. Methods of using phylogenetic systematics to reconstruct the history of the Linear B script. *Archaeometry* 50:158-176.

Smith, A. C. 2005. The politics of weddings at Athens: an iconographic assessment. *Leeds International Classical Studies* 4.01:http://www.leeds.ac.uk/classics/lics/2005/200501.pdf.

—. 2006. The evolution of the Pan painter's artistic style. *Hesperia* 75:435-451.

Sourvinou-Inwood, C. 1975. Who was the teacher of the Pan painter? *The Journal of Hellenic Studies*:107-121.

Sowerby, R. 1995. *The Greeks*. London: Routledge.

Sparkes, B. A. 1981. Not cooking, but baking. *Greece & Rome* 28:172-178.

—. 1991. *Greek art*. Oxford: Oxford University Press.

—. 1996. *The red and the black: studies in Greek pottery*. London: Routledge.

Spivey, N. 1991. "Greek vases in Etruria," in *Looking at Greek vases*. Edited by T. Rasmussen and N. Spivey, pp. 131-150. Cambridge: Cambridge University Press.

Stager, J. M. S. 2005. "Let no one wonder at this image": A Phoenician funerary stele in Athens. *Hesperia* 74:427-449.

Stansbury-O'Donnell, M. D. 2006. *Vase painting, gender, and social identity in archaic Athens*. Cambridge: Cambridge University Press.

Steiner, A. 2002. Private and public: links between symposion and syssition in fifth-century Athens. *Classical Antiquity* 21:347–390.

—. 2004. The Alkmene hydrias and vase painting in late-sixth-century Athens. *Hesperia* 73:427-463.

Stewart, A. 1995. "Rape?" in *Pandora: women in classical Greece*. Edited by E. D. Reeder, pp. 74-90. Baltimore: Princeton: Walters Art Gallery; Princeton University Press.

Storey, I. C. 2005. *A guide to ancient Greek drama*. Malden, MA; Oxford: Blackwell.

Stroud, R. S. 1998. The Athenian grain-tax law of 374/3 BC. *Hesperia Supplements* 29:iii-140.

Sugiyama, M. S. 2001. Food, foragers, and folklore: the role of narrative in human subsistence. *Evolution And Human Behavior* 22:221-240.

Sutton, R. F., Jr. 2004. Family portraits: recognizing the "oikos" on Attic red-figure pottery. *Hesperia Supplements* 33:327-350.

Symons, D. 1992. "The psychological foundation of culture," in *The Adapted Mind: Evolutionary Psychology and the Generation of Culture*. Edited by L. C. a. J. T. JH Barkow, pp. 19-136. Oxford: Oxford University Press.

Tang, C. C., E. J. MacLean, M. A. Roberts, D. T. Clarke, E. Pantos, and A. J. N. Prag. 2001. The study of Attic black gloss sherds using synchrotron x-ray diffraction. *Journal Of Archaeological Science* 28:1015-1024.

Tanner, J. 1999. Culture, social structure and the status of visual artists in classical Greece. *Proceedings of the Cambridge Philogical Society* 45:136-175.

Tehrani, J., and M. Collard. 2002. Investigating cultural evolution through biological phylogenetic analyses of Turkmen textiles. *Journal of Anthropological Archaeology* 21:443-463.

Thurneyssen, J. 1979. Artists' mistakes: a reply. *International Journal of Nautical Archaeology* 8:254-254.

Tilley, A. 1997. New evidence for Greek merchantmen. *International Journal of Nautical Archaeology* 26:344-344.

Topper, K. 2007. Perseus, the maiden Medusa, and the imagery of abduction. *Hesperia* 76:73-105.

Trendall, A. D. 1960. The Cassandra painter and his circle. *Jahrbuch der Berliner Museen* 2:7-33.

—. 1974. *Early south Italian vase-painting*. Mainz: von Zabern.

Trivers, R. 1985. *Social evolution*. Menlo Park, California: Benjamin/Cummings.

Turnure, J. H. 1981. Again, dirty trick vases. *American Journal Of Archaeology* 85:175-177.

Vickers, M. 1980. Another dirty trick vase. *American Journal of Archaeology* 84:183-184.

—. 1985. Artful crafts: the influence of metal work on Athenian painted pottery. *The Journal of Hellenic Studies* 105:108-128.

—. 1987. Value and simplicity: eighteenth-century taste and the study of Greek vases. *Past and Present*:98-137.

—. 1990. Golden Greece: relative values, Minae, and temple inventories. *American Journal of Archaeology* 94:613-625.

Vickers, M., and D. Gill. 1994. *Artful crafts: ancient Greek silverware and pottery*. Oxford: Clarendon Press.

Vogeikoff-Brogan, N. 2000. Late Hellenistic pottery in Athens: a new deposit and further thoughts on the association of pottery and societal change. *Hesperia* 69:293-333.

Volkov, I., J. R. Banavar, S. P. Hubbell, and A. Maritan. 2003. Neutral theory and relative species abundance in ecology. *Nature* 424:1035-1037.

von Bothmer, D. 1972. Greek vase painting: an introduction. *The Metropolitan Museum of Art Bulletin* 31:3-9.

Waldbaum, J. C., and J. Magness. 1997. The chronology of early Greek pottery: new evidence from seventh-century BC destruction levels in Israel. *American Journal of Archaeology* 101:23-40.

Walker, H. J. 1995. *Theseus and Athens*. New York; Oxford: Oxford University Press.

Watts, D. J., and P. S. Dodds. 2007. Influentials, networks, and public opinion formation. *Journal of Consumer Research* 34:441-458.

Webster, T. B. L. 1972. *Potter and patron in Classical Athens*. London: Methuen & Co Ltd.

Wells, P. S. 1980. Contact and change: an example on the fringes of the classical world. *World Archaeology* 12:1-10.

Welz, G. 2003. The cultural swirl: anthropological perspectives on innovation. *Global Networks-A Journal Of Transnational Affairs* 3:255-270.

Whiten, A. 2000. Primate culture and social learning. *Cognitive Science* 24:477-508.

Whitley, J. 1997. Beazley as theorist. *Antiquity* 71:40-47.

—. 2001. *The archaeology of ancient Greece*. Cambridge: Cambridge University Press.

Williams, D. 1991. "The drawing of the human figure on early red-figure vases," in *New perspectives in early Greek art*. Edited by D. Buitron-Oliver, pp. 285-301. Washington, D.C.: National Gallery of Art.

—. 1996. Refiguring Attic red-figure: a review article. *Revue archeologique* 2:227-252.

Williams, D., and L. Burn. 1991. "Vase-painting in fifth-century Athens," in *Looking at Greek vases*. Edited by T. Rasmussen and N. Spivey, pp. 103-130. Cambridge: Cambridge University Press.

Wolff, J. 1981. *The social production of art*. London: Macmillan.

Wölfflin, H. 1956. *Principles of art history: the problem of the development of style in later art / translated by MDHottinger [from the 7th German ed., 1929]*. New York: Dover.

Woodford, S. 1974. More light on old walls: the Theseus of the Centauromachy in the Theseion. *The Journal of Hellenic Studies* 94:158-165.

—. 1989. Herakles' attributes and their appropriation by Eros. *The Journal of Hellenic Studies* 109:200-204.

Woodford, S., and M. Loudon. 1980. Two Trojan themes: The iconography of Aiax carrying the body of Achilles and of Aeneas carrying Anchises in black figure vase painting. *American Journal of Archaeology* 84:25-40.

Wyly, B. J. 1998. Competition in Scholarly Publishing? What Publisher Profits Reveal. *Association of Research Libraries Bimonthly Newsletter* 200:http://www.arl.org/bm~doc/wyly.pdf.

Yule, G. U. 1925. A Mathematical Theory of Evolution, Based on the Conclusions of Dr. J. C. Willis, F.R.S. *Philosophical Transactions of the Royal Society of London. Series B, Containing Papers of a Biological Character* 213:21-87.

Zanette, D. H., and S. C. Manrubia. 2001. Vertical transmission of culture and the distribution of family names. *Physica A* 295:1-8.