DIGITAL CEMENTUM LUMINANCE ANALYSIS AND THE HAUA FTEAH HOMININS: HOW SEASONALITY AND SEASON OF USE CHANGED THROUGH TIME*

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The importance of environmental seasonality and the seasonal cycling of resources to human populations make studies of human responses to seasonality useful to test hypotheses about short- and long-term changes in human behaviour. This paper utilizes digital dental cementum luminance analysis in order to better understand patterns of the seasons of death of Ammotragus lervia at Haua Fteah, Cyrenaica, and to test whether long-term climatic changes can be detected in dental cement. The overall pattern of the season of death of A. lervia at Haua Fteah is that of year-round utilization, with a slight increase over time in A. lervia use during the growth period/summer time. The use of digital cementum luminance analysis (DCLA) to detect changes in the seasonal differences between temperatures indicates a trend for increased seasonality in temperature over the past 40,000 years at Haua Fteah. Furthermore, DCLA patterns in the more recent assemblages indicate a shift to a warmer climate from Marine Oxygen Isotope Stage (MIS) 3 to MIS 1.

KEYWORDS: SEASONALITY, HAUA FTEAH, DIGITAL CEMENTUM LUMINANCE ANALYSIS

INTRODUCTION

The Haua Fteah site in Cyrenaica, northern Libya, is particularly important to palaeoanthropologists for a number of reasons. Its location in north-east Africa (Fig. 1) provides proximity to possible corridors out of Africa as well as providing access into the Mahgreb, and could present evidence as to population fluctuations and movements in these key areas. Furthermore, Haua Fteah’s long archaeological record spanning the Middle Palaeolithic through to the Neolithic, combined with the fossil remains of early modern H. sapiens, presents evidence that the relationship between behavioural modernity and morphological modernity is in fact quite complex. A better understanding of the seasonality shifts in faunal use between technological assemblages at Haua Fteah could provide a better understanding of H. sapiens dispersals and patterns of innovation, and this research hopes to illuminate the seasonal strategies of the Haua occupants through time.

In addition, seasonality studies utilizing dental cement are enhanced by the quantitative evaluation of luminance profiles (Wall-Scheffler and Foley in press). The study of luminance allows the researcher to assess not simply the season of and age at death of faunal remains, but also to interpret seasonal changes over time. Differences between the intensity of low-luminance (LL) and high-luminance (HL) bands have been shown to increase in conjunction with increasing
differences between known summer and winter temperatures (Wall-Scheffler and Foley in press). The highly significant predictive relationships between luminance and temperature among modern ungulates can now be tested at a site that covers a wide temporal period and that has a considerable number of samples. If successful, this research will reveal long-term climate changes in a discrete area and should clarify our understanding of the environment to which anatomically modern humans in Cyrenaica had to adapt.

FAUNAL REMAINS

The faunal evidence indicates that the primary distributors of the remains found at Haua Fteah were humans only (Higgs 1967; Klein and Scott 1986). There is little evidence of even gnawing by other carnivores or rodents, and it is likely that the huge cave opening and high roof, as well as the significant amount of light reaching the cave’s interior, provided deterrents for other predators (Higgs 1967). As with many other North African sites, Ammotragus lervia (commonly referred to as Barbary sheep or aoudad) remains dominant through every cultural level.

The geographical location of Haua Fteah and the abundance of A. lervia in the area are likely to contribute to the dominance of A. lervia throughout the assemblages. At another Cyrenaican site—Hagfet et Tera—gazelle is far more dominant: this is almost certainly because the site is alongside the desert and an area with far more gazelle than A. lervia (Klein and Scott 1986). Similarly, sites in the area immediately surrounding Haua Fteah—Sidi el Hajj Creiem and Hagfet ed Dabba—have somewhat similar faunal assemblages to those found at Haua. These characteristics do suggest that, at least until the Neolithic, immediate foodstuff availability in a given area probably contributed to site location, faunal selection and perhaps...

Figure 1  An aerial photograph showing the location of Haua Fteah in Cyrenaica, Libya (image provided by Google Earth).
even population dispersal. Along these lines, topography and species availability are decidedly similar between the Maghreb and Cyrenaica, but between either of these two locales and the Nilotic region to the east, there are many differences, especially in wild ungulates (Klein and Scott 1986), and, accordingly, human populations show significant differences in technology (Iovita 2002). Understanding the seasonal patterns between technological assemblages at Haua may provide data that can later help to illuminate population dispersals between the Maghreb and Cyrenaica, and to explain the technological assemblage similarities between the two regions and the differences between Cyrenaica and the Nile.

The sequence at Haua Fteah has been divided into cultures or phases by previous scholars (McBurney 1967, 1968; Klein and Scott 1986) and includes the Middle Palaeolithic (the Aterian and Mousterian), the Upper Palaeolithic (the Dabban, Eastern Iberomaurusian and Libyco-Capsian), the Neolithic and the Historic. Due to the nature of the original excavation of the site (for illustrations, see McBurney 1967), precision in the assignment of artefacts and faunal remains to exact cultural layers can be difficult to attain. It remains necessary to return to McBurney’s (1967) original work and try to use spit number and layer level to recreate cultural context. In the event that lack of precision might still remain, samples from overlapping areas have been avoided as much as possible. Because of the overlap, however, and for ease of analysis, sample grouping will occur by technological type (following Klein and Scott 1986).

**MATERIALS AND METHODS**

**Dental cementum preparation**

*Ammotragus lervia* teeth from each assemblage were collected in order that an analysis of the luminance properties of dental cementum bands could be accomplished. Each tooth was embedded in resin and sliced longitudinally down the centre, and each cut face was polished. Each half was then affixed to a frosted slide with more of the same resin (Buehler Epo-thin epoxy) and left to dry overnight. Once dry, the remaining tooth was sliced off and the thin section ground down and polished to $70 \pm 10 \mu m$.

Upon completion, each thin section was viewed using a polarizing microscope. Polarizing light microscopes that utilize transmitted light are regarded as superior to reflected light microscopes, as they allow finer histological details to be seen (Hillson 1986): in addition, previous researchers have had problems using a reflected light microscope for the analysis of cement (McCullough 1996). Reflected light reveals superficial detail whilst polarized light transmitted through the specimen is being scattered by the structural properties of the cementum, thus revealing more detail than the reflected light microscope (see further description in Burke 1993). Furthermore, a polarizing set-up is crucial for Palaeolithic zooarchaeologists in assessing the appearance of diagenetic samples among faunal remains (Stutz 2002).

The microscope used for this research is a Leica DM EP with 10× and 20× objectives and a rotating stage that can be used to align the sample with the polarizing lenses. The optical properties of cementum can vary depending upon the orientation of the sample to the polarizers (for a detailed explanation, see Stutz 2002). To create consistency in the optical properties of each sample, the protocol consisted of lining each sample up to one of the perpendicularly oriented polarizers, so the first cementum band after the layer of Tommes would appear as a high-luminance (HL) band (Lieberman 1994). Under polarizing microscopes, HL bands of this population represent summer, or fast-growth, periods, while low-luminance (LL) bands represent winter, or slow-growth, periods.
A Nikon Coolpix 5000 with 12× magnification was attached to the microscope. The entirety of cementum tissue on each tooth was assessed for areas of complete cementum (e.g., no damage to the outer edges), which also exhibited high contrast between HL and LL bands. All areas of high contrast were photographed and the point on the thin section and the photo given the same identification, to which they could be referred when necessary.

Luminance graphs and numerical values for each HL and LL band were then collected using the MATLAB program, following the protocol laid out in Wall and Wall (2006) and Wall-Scheffler and Foley (in press).

**Diagenesis analysis**

The use of dental cementum to assess the season of death of faunal remains has been shown to be successful to Palaeolithic archaeology once a detailed analysis of the appearance of diagenetic samples has been accomplished (Stutz 2002). Following Stutz (2002), an analysis of diagenesis was undertaken; the samples used for this analysis and the appearance of diagenetic or unusable (due to the loss of the outer edge) individual teeth are listed in Table 1. As the occurrence of diagenetic or unusable teeth was not prevalent, a thorough analysis of *A. lervia* remains was deemed appropriate.

**Age analysis**

In order to look at patterns between assemblages, age cohorts will be utilized for some analyses. The age cohorts are defined based on Cassinello (1997) and include calves (0–11 months), infants (12–23 months), juveniles (from 2 years to 2 years 11 months), sub-adults (from 3 years to 3 years 11 months), prime (from 4 years to 7 years 11 months) and post-prime (more than 8 years old). The cohort decisions are based on data from body size, horn size, teeth maturation and dominance relationships.

**Minimum number of individuals**

In regards to the minimum number of individuals (MNI) count, the following restrictions are applied. If the samples are from different assemblage layers, they are considered to be different individuals. If the samples are from differently dated spits, they are considered to be different individuals.
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individuals (Close 1977). Furthermore, if the samples are of different ages and seasons of death, they are considered to be different individuals. If all these factors remain the same between samples, a paired samples t-test is run between the luminance properties of the similar samples. If the luminance values are significantly similar and correlated, the samples are considered to be from the same individual; if the values are not significantly correlated and follow divergent luminance patterns, the samples are considered to be from different individuals. This follows a similar method utilized by Pike-Tay (1991, 1999) and the use of luminance values allows for a statistically robust assessment of MNI counts. It is hardly surprising that each tooth nearly always represents an individual: the sample presented here is only a small portion of the entire excavation—much was left behind in Libya. Furthermore, the entire excavation was only a small portion of the entire cave.

The remaining sample is one of the largest collections ever assembled for a Palaeolithic seasonality analysis using dental cementum, and each technological grouping alone has more ‘individuals’ than entire studies accomplished previously. Nonetheless, some technological assemblages do contain fewer samples than would be ideal, especially the Middle Palaeolithic and early Upper Palaeolithic assemblages. This is probably caused by numerous issues, including sampling error as well as the possibility of less intense usage of Haua during Marine Oxygen Isotope Stage (MIS) 5 to MIS 3, as suspected by McBurney (1967).

Statistics

The two types of statistics primary utilized in this study were t-tests and linear regressions. The t-tests were run to compare season of death and age results between technological assemblages and seasonal periods in order to tease apart significant differences in resource acquisition. Linear regressions were used to detect the possibility of predictive relationships between A. lervia death and age results, archaeological findings and time reconstructions, in order to gain a better understanding of under what conditions A. lervia were particularly hunted, and whether there were any particular circumstances that made them more or less vulnerable to being killed. The goal was to reconstruct any change in the patterns of use through time.

RESULTS

Season of death

Over 65% of the viewable A. lervia samples had a season of death during a growing period, as evidenced by a final band of an HL nature (see Table 2). This first result supposes a similar pattern through time and a similar response by the human populations to A. lervia.

The technological assemblages were given numerical representations (0–5) and analysed in relation to the season of death of the A. lervia sample. Independent t-tests showed highly significant differences between technological assemblages and the season of death (p = 0.017). The most obvious differences occur between Historic and all pre-Historic periods (p = 0.002) (see Fig. 2).

Even when comparisons between adjacent assemblages only are made, there remains a significant negative correlation between the season of death and technological assemblages (chi-square, $p = 0.002$), implying that pre- and post-Historic differences are not the only source of inter-site season of death variation. When considering each assemblage on its own, it further becomes clear that the shift from pre-Historic to Historic did not necessarily transpire...
in gradual stages: the abrupt transitions between the seasons of death of each assemblage are significant (see Figs 3 and 4 and Table 1).

**Age at death**

The ages at death at Haoua Fteah are of primarily prime-aged animals (for a whole-site and all-seasons histogram, see Fig. 5). There is not a significant relationship between age cohorts
and season of death ($p = 0.167$), nor a significant relationship between the age cohorts and technological assemblages ($p = 0.236$), seemingly implying that *A. lervia* of prime ages were killed by every population resident at Haua Fteah. Furthermore, using Kolmogorov–Smirnov tests, there are no significant differences between the age profiles of any of the technological assemblages, nor between the different seasons of the same assemblage.

Nonetheless, *A. lervia* killed during the summer months are significantly younger than those killed during the winter months ($p = 0.04$). Furthermore, age cohorts killed during the summer months alone are significantly correlated with technological assemblages ($p = 0.022$), a relationship which is not significant between winter deaths ($p = 0.348$).

Taken together, the highly significant correlations between technology and season of death, combined with the significant associations between the age at death of the summer kills and technological assemblages, imply that interactions between human populations and *A. lervia* do alter seasonally. It seems especially the case that differences between populations occurred during the summer months.

**Climate change over time**

Regressions run between technological assemblages and cementum histology (as measured through HL and LL values) do not show particularly high coefficients of determination, but LL bands’ luminance values are highly significantly correlated with technological assemblages.
The positive $\beta$-value signifies that later technological assemblages correlate with darker LL bands (probably laid down in winter). This implies a shift over time, and that at the time of the Historic assemblages, LL bands are significantly darker bands than those from the Upper or Middle Palaeolithic assemblages. Earlier work on modern ungulates has shown (Wall-Scheffler and Foley in press) that such a luminance trend implies an increase in warmer temperatures over time, especially during the summer months. This corroborates Barker’s (1996) evidence for climatic change from MIS 3 to the present in Cyrenaica.

Earlier work has also shown that changes in seasonality variables can be detected through the ratio of summer to winter luminance (Wall-Scheffler and Foley in press). Indeed, the ratio of summer to winter luminance of *A. lervia* is significantly predicted by the known radiocarbon dates ($p = 0.012$, $\beta = -0.120$). Since increasing temperature-seasonality correlates with an increasing gap between summer and winter luminance (Wall-Scheffler and Foley in press), the negative beta value implies that as time moves forward, the gap between summer and winter luminance increases and thus provides evidence for an increase in Cyrenaican seasonality from the Palaeolithic to the Historic periods.

Luminance values also have significant correlations with the age at death of *A. lervia* individuals: as average HL-band values decrease, age at death slightly increases ($p = 0.011$, $\beta = -0.286$), whilst as average LL-band values rise, age at death also increases ($p < 0.001$, $\beta = 0.450$). These results indicate that large differences between summer and winter luminance represent a characteristic that makes prime-aged *A. lervia* individuals more likely to be killed.

Figure 4 This graph indicates larger patterns over time by considering each assemblage as a whole in comparison with other levels. This graph shows some indication that the large-scale differences between pre-Historic and Historic periods actually appear to occur quite rapidly. Furthermore the Libyco-Capsian period shows minimal winter deaths—a very unexpected phenomenon due to the general consensus that Haua was continually occupied through the seasons.
As large differences between summer and winter luminance are correlated with increased seasonality of temperatures, it appears that during times of increased seasonal variations, hominin populations at Haua Fteah were more likely to actively hunt prime-aged *A. lervia*. Since *A. lervia* are less susceptible to the effects of harsh, highly seasonal environments (Simpson and Gray 1983; Cassinello 1998), they are a likely resource. This offers support to Klein and Scott’s (1986) claim that increases in *A. lervia* in the Haua Fteah record generally imply inhospitable climates and a decrease in the availability of cattle or other bovids.

As both the environmental shifts and the technological associations occur over periods of time, it remains possible that the differences between assemblage levels are simply demonstrative of differences between environmental shifts occurring through time and are not necessarily due to differences in *H. sapiens* occupation. Nonetheless, the dramatic shift between the Neolithic and the Historic period and the singular occurrence of primarily growth-period kills from the Libyco-Capsian assemblages indicate that both climatic shifts and differences in hominin strategies may account for the significant differences between technological assemblages and *A. lervia* remains.

DISCUSSION

This study has thus added to an understanding of the nature of transitions between technological assemblages. Visually, the most abrupt shifts in the seasonal use of *A. lervia* come between the Historic and the pre-Historic periods as well as the assemblages surrounding the Libyco-Capsian;
however, there are significant differences between all assemblages and the season of death of *A. lervia* found in each assemblage. On the basis of the nature of the predictive statistics, it remains possible that the significant differences between assemblages occurred simply because of changes in the environment; however, *A. lervia* is notorious for its adaptive abilities and as the assemblages are the primary result of human interaction, an equally parsimonious explanation is that the shifts in *A. lervia* usage are due to shifts in human hunting.

What is apparent is that differences between each of the pre-Historic periods are not as extreme as the difference between the Neolithic period and the Historic period. A major contribution to the smaller pre-Historic variations may simply be the difference between summer and winter strategies. For example, the small number of winter kills from the Libyco-Capsian levels may not be particularly surprising; it is possible that Libyco-Capsian populations utilized another area for winter resources.

In terms of the summer use of Haua Fteah, all the age patterns are consistently prime-aged, though the Dabban has the most variation of all the summer assemblages, with a number of juveniles and yearlings; it is possible that this implies summer kills of mothers and their young during the period when they are on their own and at their most vulnerable. Of course, the small sample size and the inability to sex the remains prevent the drawing of extensive conclusions.

Both the Eastern Iberomaurusian and the Libyco-Capsian show striking similarities between their summer age profiles and perhaps provide Close (1977, 1986) with additional information to her acknowledgement of a gradual (rather than sudden, as originally proposed by McBurney) shift between these two populations. The near absence of Libyco-Capsian remains attributable to winter months could either be a sampling error or, as just mentioned, could simply mean that Libyco-Capsian populations utilized other areas during the winter months. Despite the absence of distinctly seasonal bird species, the initiation during the Libyco-Capsian period of utilizing diverse and numerous bird species suggests that the Libyco-Capsian population may have been exploiting birds more frequently than previous populations (MacDonald 1997), especially if they did continue to populate the area during the winter months.

The Neolithic summer age profile presented here is not particularly similar to the catastrophic profile assessed by Klein and Scott (1986) and the Neolithic populations seem to continue the capture of primarily prime-aged animals. The continuation of bird usage through the Neolithic might also evidence more woodland habitats near Haua Fteah, as well as emphasizing the increased diversity of food acquired during the Neolithic period (MacDonald 1997).

Hardly unexpectedly, the Historic assemblage is quite different from the levels immediately overlying, though because of the small sample it remains difficult to make a clear judgement of patterns of use or the possibility of management.

On the basis of the technological assemblages, as well as the faunal evidence, Haua Fteah offers evidence for multiple population dispersals and replacements. Despite no evidence of *H. sapiens* reaching Europe through the Maghreb and Gibraltar, it does seem apparent that *H. sapiens* were dispersing west towards the Maghreb itself and Haua Fteah was along one route that was utilized. Furthermore, the distinct differences between the technologies at Haua Fteah and in the Levant (Iovita 2002) indicate that dispersals to Cyrenaica and the Maghreb may have been unique populations that did not spread out of Africa at all. Further studies of other Cyrenaican sites and the relationship between these assemblages and ones further west could offer important evidence as to African dispersals of *H. sapiens*.

The very small samples from specific periods do demand a qualification and the hypotheses presented above should be viewed as simply a preliminary suggestion based on the available
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Further investigation into Haua and into the surrounding areas will be vital in order to completely understand the possibilities of shifting procurement strategies, the seasonal use of resources by different populations, and the relationships between populations dispersing through Cyrenaica and the Mahgreb.

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