Journal of Archaeological Science: Reports 56 (2024) 104541

Contents lists available at ScienceDirect

Journal of Archaeological Science: Reports

journal homepage: www.elsevier.com/locate/jasrep

Cooked or discarded? Experimental distinction of rabbit burnt bones and its application to the archaeological record

Goizane Alonso [a,*], Anna Rufà [b,c], Ruth Blasco [d,e]

[a] Universidad de Burgos (UBU), Calle Don Juan de Austria 1, 09001 Burgos, Spain
[b] Interdisciplinary Center for Archaeology and the Evolution of Human Behaviour (ICArEHB), FCHS – Universidade do Algarve, Campus de Gambelas, 8005-139 Faro, Portugal
[c] Université de Bordeaux, CNRS, MCC, PACEA, UMR 5199, 33600 Pessac, France
[d] Institut Català de Paleoecologia Humana i Evolució Social (IPHES-CERCA), Spain
[e] Universitat Rovira i Virgili, Departament d'Història i Història de l'Art, Spain

ARTICLE INFO

Keywords:
Small prey
Rabbits
Burnt bones
Experimental archaeology

ABSTRACT

Leporid bones from Middle Palaeolithic assemblages may result from the contributions of various predators, including humans, or natural processes. Although the acquisition, processing, and consumption of small mammals by Neanderthal groups has been widely demonstrated, there are still some unresolved issues. Cut marks are typically the most reliable indicators of human processing of carcasses. However, animals the size of rabbits often pose a challenge in this regard, as the use of stone tools is not always necessary for their consumption, particularly for meat or marrow extraction. Consequently, the quantity of these types of marks, such as cuts or hammer-stone percussion damage, indicating human processing, may be limited. Burning is another type of bone damage that could be indicative of human action, although both intentional and accidental processes could lead to the thermal alteration of remains without necessarily linking them to consumption. Therefore, efforts to distinguish the processes resulting in bone burning are of vital importance in determining the origin of these animals in archaeological assemblages. In this work, the results of several experimental series designed to characterise the roasting and subsequent cleaning of waste on rabbit bones are presented. These results confirm most of the characteristics described in previous experimental works on burnt bones, highlighting the differential damage between bones with and without meat. The current study aims to contribute new data for characterising burned rabbit bones resulting from human actions, which can then be applied to Middle Palaeolithic assemblages with this type of thermal alteration bone modifications.

1. Introduction

Several zooarchaeological studies have demonstrated that small prey, such as rabbits, birds, and tortoises, contributed to Neanderthal diets to varying degrees, depending on different variables, such as their availability in the environment (Speth and Tchernov, 2002; Blasco, 2008; Sanchis and Fernández-Peris, 2008; Blasco and Fernández-Peris, 2009; Bocherens, 2009; Blasco et al., 2011; Hardy and Moncel, 2011; Peresani et al., 2011; Blasco and Fernández-Peris, 2012a, 2012b; Cochard et al., 2012; Rufà et al., 2014, 2016; Sanchis et al., 2015, 2016; Blasco et al., 2016; Laroulandie et al., 2016; Carvalho et al., 2018; Morin et al., 2019; Nabais and Zilhão, 2019; Nabais, 2021). Therefore, understanding how these small vertebrates were exploited is essential for shedding light on Neanderthal subsistence and their interaction with the environment. The taphonomic pattern resulting from human processing activities and consumption of these animals is not always like that observed in larger ungulates. In the case of cut marks, for example, it is important to emphasize that the small size of prey makes the use of stone tools unnecessary for direct consumption. After skinning or feather removal, the most effective way to remove the meat, grease, and cartilage from the bones is through the direct use of hands and teeth. Consequently, cut marks are not usually abundant (sometimes practically non-existent) in most assemblages (e.g., Hockett and Haws, 2002; Cochard and Brugal, 2004; Sanchis and Fernández-Peris, 2008; Blasco et al., 2013; Rodríguez-Hidalgo et al., 2013a; Rosado-Méndez et al., 2019; Real, 2020; Blasco et al., 2022). Similarly, human gnawing marks could often be confused with those generated by other small carnivore predators, making it a challenge to interpret the origin of their

* Corresponding author at: Universidad de Burgos (UBU), Calle Don Juan de Austria 1, 09001 Burgos, Spain.
E-mail address: goizaneac@gmail.com (G. Alonso).

https://doi.org/10.1016/j.jasrep.2024.104541
Received 23 January 2024; Received in revised form 11 April 2024; Accepted 16 April 2024
Available online 30 April 2024

accumulations (e.g., Landt, 2007; Delaney-Rivera et al., 2009; Saladié et al., 2013). Thermal alteration could be another taphonomic signal that helps us determine the origin of these animal accumulations. However, burning damage can result from various processes that are not always associated with human activity and, therefore, efforts are required to differentiate between natural or accidental causes and intentional anthropogenic ones (e.g., roasting meat or cooking; Lloveras et al., 2009b). In this context, it is fundamental to identify a cognisable taphonomic pattern that can distinguish between anthropogenic fire use on bones, such as meat roasting, the use of bones as fuel, or bone discard (e.g., Costamagno et al., 2005; Yravedra and Uzquiano, 2013; Yravedra et al., 2017). In this study the focus was set on rabbit (*Oryctolagus cuniculus*) bones, as they exemplify this problem well, and they were common prey for both nonhuman (Schmitt, 1995; Hockett, 1996; Sanchis, 2000; Cochard, 2004a, 2004b; Lloveras et al., 2008, 2009a, 2011, 2012, 2014,2018a, 2018b; Mallye et al., 2008; De Cupere et al., 2009; Sanchis and Pascual Benito, 2011; Rodríguez-Hidalgo et al., 2013b, 2015; Krajcarz and Krajcarz, 2014; Arriaza et al., 2017; Arilla et al., 2020) and human predators during the early Late Pleistocene in the Iberian Peninsula (e.g., Hockett and Bicho, 2000; Sanchis and Fernández-Peris, 2008; Brown et al., 2011; Blasco and Fernández Peris, 2012a, 2012b; Hardy and Moncel, 2011; Blasco et al., 2013; Hardy et al., 2013; Rufà et al., 2014; Carvalho et al., 2018; Pelletier et al., 2019).

Many scholars have observed a strong relationship between colouration changes and the intensity of burning (Shipman et al., 1984; Stiner et al., 1995; Costamagno et al., 2005, 2009; Ellingham et al., 2015). Nicholson (1993) documented a colour progression of bones – brown through black, grey, bluish white, white– heated to a range of temperatures between 200 °C and 900 °C. Bones exposed to lower temperatures showed brown colouration, while bones burnt at temperatures of 700–900 °C presented white colourations. More recently, Gallo and colleagues (2023) noted that heat-altered bones displayed grey and white colourations when exposed to high temperatures. High degrees of burning on bones might suggest intentional disposal into the fire, whereas carbonised bones would likely result from roasting activities, as flesh protects the bone from the heat (Ellingham et al., 2015, 2016). Some authors have suggested that the presence of double colourations on rabbit bone ends could be an indicator of meat roasting (Lloveras et al., 2009b; Sanchis, 2010; Blasco et al., 2013). For instance, burning damage on the ends of the bones and not on the shafts could indicate that the bones were disarticulated before burning (Gifford-González, 1989). Consequently, heat would affect more intensely to those parts not protected by soft tissues, producing a pattern of different colours through the bone. On the other hand, a uniform colouration pattern would be expected on de-fleshed elements directly exposed to the fire (e.g., Asmussen, 2009). However, burnt bones from archaeological sites could also be the result of non-intentional or post-depositional processes (Bennett, 1999; Théry- Parisot, 2002; Asmussen, 2009; Yravedra and Uzquiano, 2013; Pérez et al., 2017). For example, some works describe at experimental level differential burning of bones buried at various depths (e.g., Stiner et al., 1995; Bennett, 1999; Férnandez Peris et al., 2013; Pérez et al., 2017). According to their results, there is a relationship between the degree of burning and the distance from the heat source. Thus, those bones in direct contact with the fire typically display higher degrees of burning, while buried bones become carbonised, get brown colourations, or remain unaltered. Some of the remains also display no uniform colouration, which results from the unequal transmission of heat by sedimentary particles (Bennett, 1999).

Regarding natural phenomena, Bellomo (1993, 1994) suggested that natural fires do not typically produce temperatures as high as those in a campfire. Even if they do, it is only for a brief duration, which is not sufficient to burn sediments or bones (Clements, 2010; Gowlett and Wrangham, 2013). Due to this fact, bones that are burned as a result of a wildfire may become charred, but it is uncommon for them to become calcined. However, this is relative since several studies have documented instances of natural fires reaching temperatures up to 900 °C (David, 1990; Buenger, 2003; Gowlett et al., 2017). Thus, based on current knowledge, there seems to be a notable difficulty in determining the taphonomic pattern of both natural and anthropogenic fires (Lyman, 1994). Furthermore, due to the numerous anthropogenic activities related to the use of fire, it could be difficult to ascertain the origin of burnt bones. In consequence, the study of anthropogenic accumulations is sometimes a challenging task, as they are usually the result of the superposition of different activities and occupation events–referred to as palimpsests. These constraints hinder the correct interpretation of the spatial organisation of prehistoric hunter-gatherer groups. Identifying the taphonomic signature of intentional burning would, therefore, be of utmost importance. Distinguishing between intentional fire-related activities would help to understand human behaviour based on their dietary habits and their relationship with the controlled use of fire. In this line, experimental archaeology is a useful tool for reproducing past phenomena and applying the data obtained to the fossil record (e.g., Ingersoll et al., 1977; Coles, 1979; Lyman, 1994; Baena Preysler, 1997; Mathieu, 2002; Outram, 2008; Ugan, 2008; Sanchis et al., 2011; Blasco et al., 2020). Many researchers have performed experimental combustion studies to determine the differential burning of bones (e.g., Shipman et al., 1984; Nicholson, 1993; Stiner et al., 1995; Bennett, 1999; Pérez et al., 2017; Téllez et al., 2022). In this paper, the results of an experimental programme involving rabbit bones and combustion structures and attempt to determine distinctive taphonomic patterns that can be attributed to the intentional use of fire are presented.

2. Methodology

All the experimental series were conducted in the Living Palaeolithic Natural Reserve (Salgüero de Juarros, Burgos, Castile and Leon, Spain). A total of thirteen combustion structures were carried out, divided into two separate experimental series sets (see section 2.1 for details). The size of the combustion structures ranged between 50–60 cm in diameter, as many documented Pleistocene hearths vary between 20 and 120 cm in diameter (e.g., Cain, 2005; Gowlett, 2006; Slimak et al., 2010; Fernández Peris et al., 2012). A mixture of pine and oak wood was used for combustion, as *Pinus* and *Quercus* are common genera found at Palaeolithic sites (González-Sampériz et al., 2010; Vidal-Matutano et al., 2019). The amount of firewood used for each hearth was recorded (in kg), as were the meteorological conditions. Environmental temperature and humidity percentage (%), wind direction, and speed (m/s) were documented. All the temperatures were measured in °C. A contact thermometer was used to measure the temperature of the centre of the hearth structure. Nevertheless, a caution note is needed here, as taking accurate temperature readings in the context of an open-air fire can be challenging. At the conclusion of each combustion process, when the hearth was completely cooled down, the number of remains (NR) was recorded and all the bones were macroscopically analysed. The bones were classified to anatomical level when possible. Numerous bone fragments were classified as indeterminate remains, as they could not be reliably attributed to any anatomical category. Bones were also grouped into "long bones", "flat bones" and "articular bones", in order to summarise the information for the tables. "Long bones" refers to those bones formed by a diaphysis, two metaphysis and two epiphyses; and with a well-developed medullary cavity (femur, humerus, radius, ulna, tibia, fibula, metacarpus, metatarsus, and phalanges). Flat bones are composed of two layers of compact bone, and a variable amount of spongy bone between them (vertebrae, ribs, cranium, mandible, scapula, and coxal). The "articular bones" category comprises carpal and tarsal bones, as well as patellae.

The primary criterion for identifying burnt bones is the direct observation of macroscopic colour changes on the bone surface. Several researchers have observed colour changes in bones associated with exposure to heat sources (e.g., Shipman et al., 1984; Buikstra and Swegle, 1989; Stiner et al., 1995; Bennett, 1999; Asmussen, 2009; Ellingham et al., 2015). These colour changes vary based on temperature, exposure time, oxygen availability, the type of wood used as fuel, the amount of fat/grease in the bones or the state of the bones (fresh, dry or semi-dry) (Shipman et al., 1984; Spennemann and Colley, 1989; Nicholson, 1993; Stiner et al., 1995; Bennett, 1999; Aldeias et al., 2016; Reidsma et al., 2016; Van Hoesel et al., 2019). Various colour classification methods have been proposed by different authors (see Table 1). Based on these classifications, it can be concluded that slightly burnt bones show a brown colour, while highly burnt bones display white and blue tones. Therefore, in this experimental study, the bones were grouped according to the following classification: 0) unburnt; 1) light brown; 2) brown; 3) black; 4) grey; 5) white; and 6) blue. Colour distribution, size reduction and cracking were also noted, as these could be the result of bone exposure to high temperatures (Shipman et al., 1984; Pérez et al., 2017). Multiple colourations on the same bone surface were also recorded.

Table 1
Colour categories related to temperature ranges proposed by different authors.

Reference	Stage	Temperature	Bone colour
Shipman and colleagues (1984)	Stage 1	20 °C–285 °C	Yellow
	Stage 2	285 °C–525 °C	Brown and grey
	Stage 3	525 °C–645 °C	Black and blue
	Stage 4	645 °C–940 °C	Predominantly white with shades of blue and grey
	Stage 5	>940 °C	White
Nicholson (1993)	Stage 1	Up to 200 °C	Brown
	Stage 2	300 °C–400 °C	Black
	Stage 3	500 °C–700 °C	Greyish
	Stage 4	800 °C–900 °C	White
Stiner and colleagues (1995)	Stage 1	–	Slightly burned, less than half of the bone fragment is charred
	Stage 2	–	Slightly burned, more than half of the bone fragment is charred
	Stage 3	–	Fully charred (black colour)
	Stage 4	–	Less than half of the bone fragment appears calcined (more black than white)
	Stage 5	–	More than half of the bone fragment is calcined (more white than black)
	Stage 6	–	Fully calcined (white colour)
Kiszely (1973)	Stage 1	From 220 °C	Brown
	Stage 2	From 380 °C	Black or greyish
	Stage 3	660 °C	Blueish
Johnson (1989)	Stage 1	–	Unburnt
	Stage 2	–	Scorched
	Stage 3	–	Black burnt
	Stage 4	–	Charred

2.1. Hearth samples

2.1.1. First experimental series set (hearths I–VII): Roasting meat

The first set of trials aimed to describe the combustion damage associated with roasting and consisted of replicating seven combustion structures (H-I to H-VII) (see Supplementary Figs. 1 and 2) of variable duration (see Table 2). The temperature was measured from the moment the fire was lit until it was completely cooled down. A total of eight European rabbit (*Oryctolagus cuniculus*) individuals were used (one individual per hearth, except H-VI where two individuals were used), purchased from approved butcher shops. All of them corresponded to juvenile individuals. They were already skinned and prepared for their consumption. It is worth noting that there was some variability in the distal appendicular elements. In the case of the hindlimbs, some included the metatarsals, while in other cases, they were cut through the tibiae. The forelimbs included the radius and the ulna, but not the metacarpals or phalanges. A fire was lit for each replica, and when only embers remained, the rabbits were placed on the structure (see Fig. 1A). When the meat was completely cooked, the rabbit was removed from the combustion structure. In the laboratory, all the meat was removed from the bones, rinsed in tap water, and left to dry. Once dry, the burning pattern of the bones was analysed following the colouration code described in the methodology. The length of all the bones was measured, and then they were stored for the second experimental series set.

2.1.2. Second experimental series set (hearths VIII–XIII): Waste cleaning

For the second set of trials, the aim was to replicate the cleaning of waste. To achieve this, all the rabbit bones recovered from the first experimental series set were thrown onto the embers (see Fig. 1B). In this way, six open hearths were created (H-VIII to H-XIII) (see Table 3). Once the combustion structure was built, the fire was lit (see Fig. 2A and 2B). The temperature was measured from the moment the fire was lit until it was completely cooled down. When the flames were extinguished, previously de-fleshed bones were placed on the embers (see Fig. 2C). The bones were set with no specific distribution, to simulate waste disposal. Nevertheless, pictures were taken to register the position of the bones (see Fig. 1B). Once the fire had cooled down, the combustion structure was carefully excavated to recover as many bones as possible. The bone remains were taken to the laboratory, submerged in distilled water for four hours, rinsed in tap water, and left to dry. When dry, the bones were macroscopically analysed. As for the first experimental series set, the length of the bones was measured.

3. Results

3.1. First experimental series set (hearths I–VII): Roasting meat

The total amount of firewood was 78 kg, using between 8 kg and 15 kg for each hearth. The duration of the hearths ranged from one hour and fifteen minutes to two hours and twenty-one minutes. The maximum temperature was above 900 °C in almost all cases, whereas the average temperature hardly exceeded 500 °C. Both environmental temperature and humidity showed high variability, as the experimental series were made at different seasons of the year (see Table 2). The exposure time varied between thirty minutes and one hour (see Table 2).

A total of 327 bones were recovered. Long bones represented 28.4% (NR = 93) whereas flat bones comprised 71.56% (NR = 234). All the bones were complete (except those that were previously cut by the butcher) and showed no cracking. For long bones, the average length was 51.81 mm, ranging from 35.62 mm to 63.89 mm, while flat bones showed an average length of 44.83 mm, from 29.61 mm to 62.75 mm (see Table 4). Most of the bones showed no burning damage. The highest percentage of burnt bones was registered for combustion structure IV, where 33.3% of the bones presented colouration changes (see Table 4). Nevertheless, it should be noted that the analysed sample was limited for this specific experimental hearth. Overall, burnt bones constituted less

Table 2
Parameters for the combustion structures of the first experimental series set.

Hearth	Bone state	Combustion time	Exposure time	Amount of fuel (kg)	Average temperature (°C)	Maximum temperature (°C)	Minimum temperature (°C)	Environmental temperature (°C)	Environmental humidity (%)
I	Fresh (with meat)	2 h 21 min	36 min	8	498.4	1149	91	3.5	84.6
II	Fresh (with meat)	1 h 30 min	30 min	10	456.3	957.4	30.9	4.6	91.5
III	Fresh (with meat)	1 h 40 min	39 min	10	594.8	924.3	247.7	6.7	80.7
IV	Fresh (with meat)	1 h 15 min	30 min	10	517.5	999.4	119.3	5.3	82.4
V	Fresh (with meat)	1 h 42 min	30 min	10	586.9	960.3	90.1	13.3	53
VI	Fresh (with meat)	2 h 05 min	60 min	15	290.9	691.8	92.1	8.8	77.3
VII	Fresh (with meat)	2 h 04 min	45 min	15	215.21	986.7	34.7	12.9	80

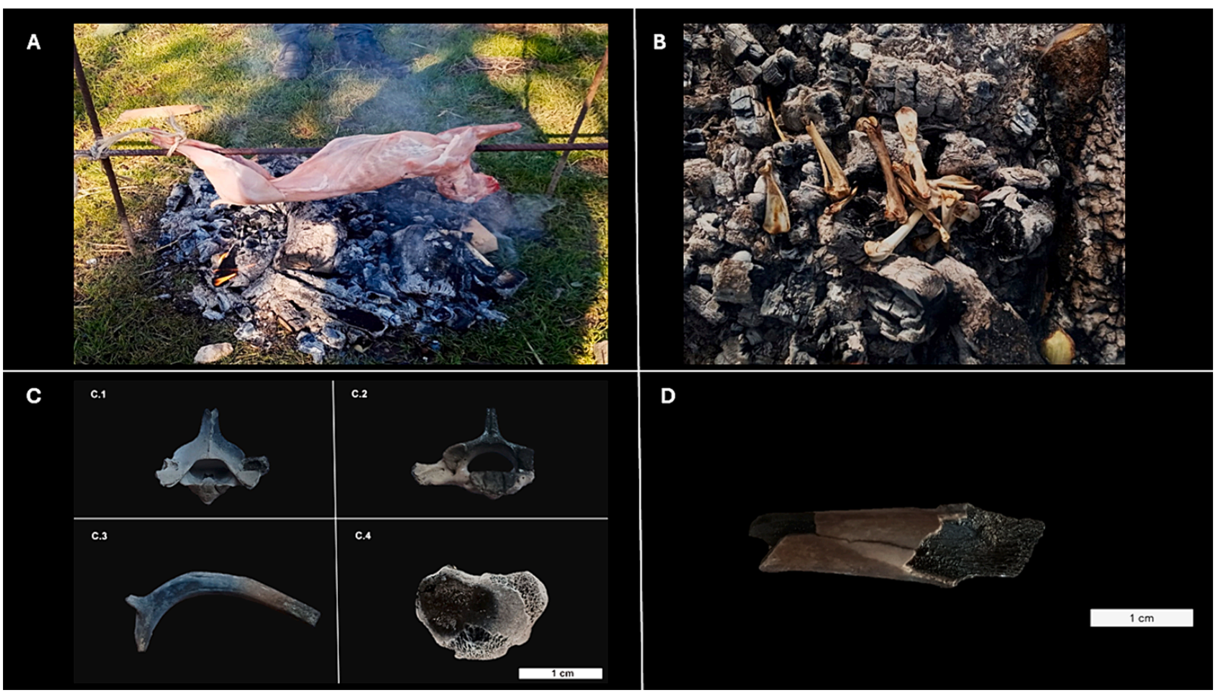

Fig. 1. **A:** Reproduction of the roasting of one rabbit individual from experimental hearth III (H-III). **B:** De-fleshed bones set on the embers of the combustion structure from the tenth experimental hearth (H-X). **C:** Multiple colourations on four bones recovered from the X (C.1, C.2 and C.3) and VIII (C.4) experimental hearths. Black and grey colourations (C.1), brown and black colourations (C.2) on two vertebrae, brown, black, and blue colouration on a rib (C.3) and black and grey colourations on an epiphysis (C.4). **D:** Differential burning degree on the inner and outer part of the same bone. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 3
Parameters for the combustion structures of the second experimental series set.

Hearth	Bone state	Combustion time	Exposure time	Amount of fuel (kg)	Average temperature (°C)	Maximum temperature (°C)	Minimum temperature (°C)	Environmental temperature (°C)	Environmental humidity (%)
VIII	Fresh	1 h 15 min	45 min	8	656.13	898.8	153.4	15.5	52.6
IX	Fresh	3 h 35 min	2 h and 15 min	15	321.9	703.2	126.4	13	90
X	Fresh	1 h 50 min	1 h 15 min	20	492.02	745.1	72.9	24.5	54.2
XI	Fresh	2 h 20 min	1 h 30 min	10	369.5	830.6	202.3	19	53
XII	Fresh	1 h 50 min	60 min	10	238.7	716.2	43.6	22.7	63
XIII	Fresh	2 h	1 h 15 min	10	396.18	541.6	88.4	26.9	58.2

than 20% of the sample. Regarding colouration changes, brown (type 2) and black (type 3) were the only observed colours. Furthermore, burning damage appeared concentrated on the distal end of some long bones, usually related to the cut made by the butcher. Colouration changes related to burning were documented on the distal end of four tibiae, one humerus and one ulna. Regarding flat bones, burning damage

Fig. 2. Progression of the combustion structure of second experimental series. **A:** combustion structure before burning. **B:** hearth during burning. **C:** rabbit bones set on the embers.

Table 4
Measurements and surface modifications of bones recovered from the hearths of the first experimental series set.

Hearth	NR	Long bones	Flat bones	Average length (mm long bones	Average length (mm) flat bones	Surface modifications	Burnt bone (%)	Burning code	Distribution
I	15	11	4	58.18	62.75	Colour changes	20	2 (brown)	Concentrated
II	29	17	12	44.70*	39.25	Colour changes	0	0 (unburned)	–
III	13	9	4	63.89	62.25	Colour changes	7.69	3 (black)	Concentrated
IV	6	4	2	51.25	56.5	Colour changes	33.33	2 and 3 (brown and black)	Concentrated
V	87	14	73	54.42	33.42	Colour changes	5.74	2 (brown)	Concentrated
VI	67	12	55	55.17	29.61	Colour changes	5.97	2 (brown)	Concentrated
VII	110	24	86	35.62	30.12	Colour changes	2.72	2 and 3 (brown and black)	Concentrated

* Note that the high number of unfused epiphyses lowers the average.

appeared on one scapula, two vertebrae, one incisive tooth and one rib. Uniform colourations were predominant, while double colourations were recorded in just two remains; one humerus and one incisive tooth.

3.2. *Second experimental series set (hearths VIII-XIII): Waste cleaning*

The total amount of firewood was 73 kg, using between 8 kg and 20 kg for each hearth. The duration ranged from one hour and fifteen minutes to three hours and thirty-five minutes. The maximum temperature was between 700 °C and 800 °C in all cases except in hearth XIII, where a maximum temperature of 541.6 °C was recorded. Average temperatures showed a significant variability. Both environmental temperature and humidity showed high variation, as the experimental series were made at different seasons of the year (see Table 3). The exposure time varied between forty-five minutes and two hours and fifteen minutes (see Table 3).

From the total 327 bones exposed to fire, 1051 bone fragments were recovered. Long bones represented 19.31% (NR = 203) whereas flat bones comprised 33.4% (NR = 351). 497 bones (47.29%) were classified as indeterminate remains. All the bones were highly fragmented. For long bones the average length was 24.13 mm, ranging from 16.4 mm to 29.39 mm, while flat bones showed an average length of 19.73 mm, from 16.4 mm to 35.28 mm. For indeterminate bones the average length was 9.4 mm (see Table 5). All the bones (100%) showed burning damage. For the combustion structure XIII the percentage was 99.7%, very close to the entirety of the sample. Regarding colouration changes, the most abundant types were type 3 (black) and type 4 (grey). Types 2 (brown) and 6 (blue) were also relatively common, while types 1 (light brown) and 5 (white) were usually scarce (see Table 5). A large proportion of the sample showed multiple colourations (NR = 643; 61.18%). Double colouration was found in 50.3% of the cases (NR = 529), while triple colouration was found in 10.18% (NR = 107). Quadruple colouration was documented in only seven cases (0.66%). On the other hand, a total of 408 bones (38.82%) showed uniform colouration (see Table 6). A brown line was recorded on just two remains, which stand for 0.2% of the whole sample.

4. Discussion

To determine whether the meat was removed from a bone after roasting, numerous works have evaluated the differential burning damage of fleshed, de-fleshed and dry bones. For instance, Buikstra and Swegle (1989) suggested that a uniform black colour could be associated with the burning of de-fleshed green bones, not fleshed or dry bones. It is

Table 5
Measurements and surface modifications of bones recovered from the hearths of the second experimental series set.

Hearth	NR	Long bones	Flat bones	Indeterminate bones	Average length (mm) long bones	Average length (mm) flat bones	Average length (mm) indeterminate bones	Burnt bone (%)	Type1	Type2	Type3	Type4	Type5	Type6
VIII	81	43	0	38	16.4	–	9.18	100	–	2.5	30.1	79	19.7	32.1
IX	46	18	7	21	29.39	35.28	9.52	100	–	28.2	67.4	67.4	8.7	32.6
X	142	44	67	31	19.84	18.8	8.6	100	2.81	28.16	54.22	78.16	10.56	32.39
XI	92	29	14	49	30	30.5	8.28	100	3.26	14.13	79.34	59.78	6.52	19.56
XII	352	42	137	173	21.92	16.40	9.19	100	0.28	26.42	57.38	56.25	2.27	16.76
XIII	338	27	126	185	27.26	17.44	11.6	99.7	0.59	31.65	62.13	53.25	2.66	16.27

Table 6
Uniform and multiple colouration percentages.

Hearth	NR	Uniform colouration (%)	Multiple colourations (%)		
			Double	**Triple**	**Quadruple**
VIII	81	43.2	49.4	7.4	–
IX	46	28.2	41.3	26	4.34
X	142	19.71	56.33	21.83	2.11
XI	92	32.6	53.2	11.9	2.17
XII	352	48.29	44.03	7.67	–
XIII	338	39.05	55.02	5.91	–

generally accepted that meat protects the bone from heat, so burnt bones resulting from cooking activities are expected to display a combination of different colours. Through this work, it can be concluded that fleshed bones typically do not exhibit colour changes due to burning. However, the specific bone parts exposed by the butcher's cut showed a slight brown colour (see Fig. 3). Burning damage primarily occurred on the distal shafts and ends of humeri, ulnae, and tibiae. In contrast, the parts protected by soft tissues remained unaffected and showed the characteristic cream colour of unburnt bones. The results obtained in this research align with the suggestion of Gifford-Gonzalez (1989) that flesh protects the bone from heat, leading to burn bones only on the articular ends. Similar results have been obtained by Medina and Teta (2012).

Fig. 3. Slight brown colouration on the distal end of an ulna from experimental hearth VI.

Other researchers have also proposed that specific burned areas on the extremities of the bones are associated with cooking activities (Henshilwood, 1997; Hockett and Bicho, 2000; Laroulandie, 2005; Lloveras et al., 2009b; Medina and Teta, 2012). All bones recovered from the first experimental series set were complete and did not seem to suffer any reduction in size or cracking. As observed, roasting does not appear to cause high burning damage to bones, making it challenging to identify its taphonomic pattern in archaeological bone remains. The presence of "clinker" was also documented, defined by Cain (2005, p.876) as "*the charred remains of organic material, including meat, marrow, fat, skin and hair*". The presence of this material could indicate that the bones were likely fleshed during burning. Nevertheless, organic matter is rarely preserved in archaeological contexts. For this reason, although the presence of clinker could be documented on experimental works, it might be improbable to identify it on archaeological bones.

As mentioned above, the burning of fleshless bones can result from various anthropogenic or non-anthropogenic activities. It is essential to distinguish between the burning of fresh and dry bones because colouration changes and the number of cracks could vary, depending on the amount of organic matter present on the bone remains (Pérez et al., 2017). However, recent experimental works have not found significant differences when burning fresh and dry bones (Téllez et al., 2022). Thus, there is a clear need for further experimental research on the anthropogenic use of fire. In this study, the focus is also on the disposal of waste produced after consuming the edible parts attached to bones. An important issue to consider is whether fleshless bones were complete or fractured when thrown into the embers. According to Knight (1985), bones that were complete when burnt should be calcined on the external part and carbonised on the internal part. However, as the burning process progresses, complete bones may fracture, and the heat would affect them equally on both the external and internal parts. Nevertheless, it should be considered that most experimental works on burnt bones have been focused on animals over 20 kg. It would be expected that the burning of rabbit bones would be different to that of larger prey. For the present experimental work, the rabbit bones were complete when they were thrown into the embers. When comparing the burning patterns of the external and internal parts of the bones significant differences were not found. This might be because the cortical bone of small-sized animals is relatively thin, so heat would affect both sides in a very similar way. Moreover, complete bones are likely to fracture during the burning process, as documented in the second experimental series set of the present work. Consequently, fire can reach those parts of the bones that were not previously exposed to the heat source.

As observed, more than half of the sample in each of the second-set hearth replicas (H-VIII to H-XIII) showed multiple colourations. Thus, multiple colourations are not exclusive to cooking, as burnt fresh bones can also display double, triple, and even quadruple colourations. According to Bennett (1999), multiple colourations on the same bone surface could be caused by dramatic temperature fluctuations, which would be consistent with an open-air fire context. In the same way, a chaotic pattern of multiple colourations on the same bone could also appear in buried bones, due to the differential transmission of heat through sediment particles. Through an experimental work, Pérez and colleagues (2017) demonstrated that the bones most thermally affected were those in close contact with the fire. Similarly, the bones recovered from the hearths in the second experimental set of the present work were heavily burnt, with calcination (white and white blueish colour) occurring on those bones or parts of bones closer to the heat source. As a general trend, the most common colour types were type 3 (black colour), type 4 (grey colour) and type 6 (blue colour), representing high burning degrees. Nicholson (1993) suggested that bones should display a wide variety of colours depending on their position within the combustion structure. In the second experimental series set presented in this work, bones were fresh and complete when placed onto the embers. A differential colouration pattern with higher burning colours on those bones closer to the centre of the combustion structure would be expected. However, it should be considered that the recovered bones were highly fragmented, and several remains could not be identified at the anatomical level. It was not possible to associate these fragments with an exact position inside the combustion structure. In addition, some identifiable bones were showing multiple colourations (see Fig. 1C). In some cases, higher burning degrees were recorded on the side of the bone that was in direct contact with the embers, while the opposite side presented lower burning degrees (see Fig. 1D). The data, therefore, confirm the idea of differential combustion based on the proximity to the heat source.

Exposure to high temperatures also increases the fragility of bones and makes them susceptible to fracture (e.g., Stiner et al., 1995; Lloveras et al., 2009b; Gallo et al., 2021). Bones exposed to high temperatures for a relatively long period should appear highly fragmented, due to the loss of water and the decomposition of organic matter. Moreover, burning generates changes to bioapatite crystal dimensions and structure (Gallo et al., 2021). Burnt bones undergo four stages at different temperatures. The first stage is characterised by the loss of water, and it occurs between 100 °C and 600 °C. The second stage would be the decomposition of organic matter between 300 °C and 800 °C. As a consequence of the complete degradation of organic matter, bones usually acquire grey and white colourations. Those bones could be classified as calcined bones, while blackened bones can be referenced as carbonised. Between 500 °C and 1100 °C some authors documented the growth of bioapatite crystals, defined as the inversion stage. The last stage, fusion, occurs above 700 °C and it is related to microstructural changes of bioapatite crystals (Thompson, 2004, 2015; Ellingham et al., 2015; Reidsma et al., 2016; van Hoesel et al., 2019). As a consequence, burnt bones are more fragile than unburnt bones, and they often display cracks and fragmentation (Spennemann and Colley, 1989; Costamagno et al., 2005; Hanson and Cain, 2007; Mentzer, 2009; Pérez et al., 2017). In the experimental trials presented in this work, a significant difference was observed in the length of both long and flat bones between the first and the second sets (see Fig. 4 and Fig. 5). As shown in the previous paragraphs, the bones recovered from the first set were complete and did not show any signs of cracking. On the other hand, fleshless bones exposed to high temperatures from the second set appeared highly fragmented. In fact, a great number of bones could not be identified to anatomical level. As shown in Table 7, several bones were classified as long bones, as they were diaphyseal fragments that could not be attributed to any particular bone. It should be noted that the rabbit individuals used for this experimental work were all immature individuals. For this reason, as the epiphyses were not completely fused, they were easily separated from the diaphysis of the bones due to burning. Concerning dental elements, various molars and incisive were de-attached from mandibular and maxillary bones. Except for hearth XI, more bones were recovered from the second hearth set than from the first one. It can be concluded that burnt bones can appear highly fragmented, and they have to be classified in a broader anatomical category, or even classified as indeterminate remains. Burnt bones are extremely fragile and often have a glassy appearance. Some bones also broke during the analysis in the laboratory. When this occurred, the fragments were kept together in the same plastic bag. Additionally, it was observed that a significant number of bones from the second set were less than 20 mm in length. Therefore, it is important to focus on the small burnt remains from archaeological sites, as they could be associated with the use of fire for other anthropogenic activities rather than cooking, such as cleaning purposes.

In summary, the data obtained in this experimental work is consistent with the idea that roasted meaty rabbit bones may remain unburned, as supported also by previous research. It is unlikely that archaeological bones showing high burning degrees are the result of cooking activities. Instead, they could be the consequence of accidental exposure of fleshless bones to the heat source (Shipman et al., 1984; Blasco, 2008), the use of bones as fuel or the cleaning of waste (Théry-Parisot, 2002; Costamagno et al., 2005; Théry-Parisot et al., 2009; Marquer et al., 2010; Yravedra and Uzquiano, 2013). However, distinguishing between these activities may be challenging, as they may produce very similar taphonomic patterns, as well as it could potentially hide earlier activities related to the roasting of meat before its extraction.

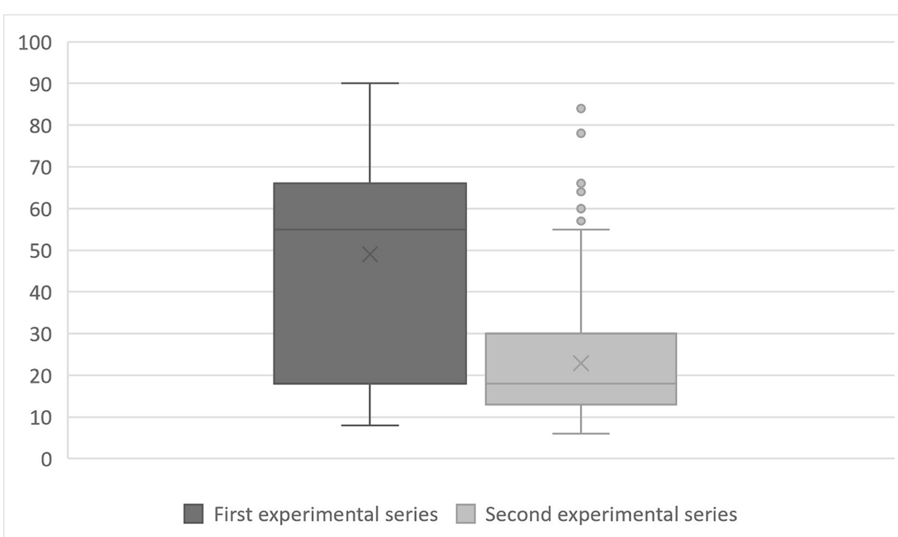

Fig. 4. Length differences (in mm) for long bones of first and second experimental series.

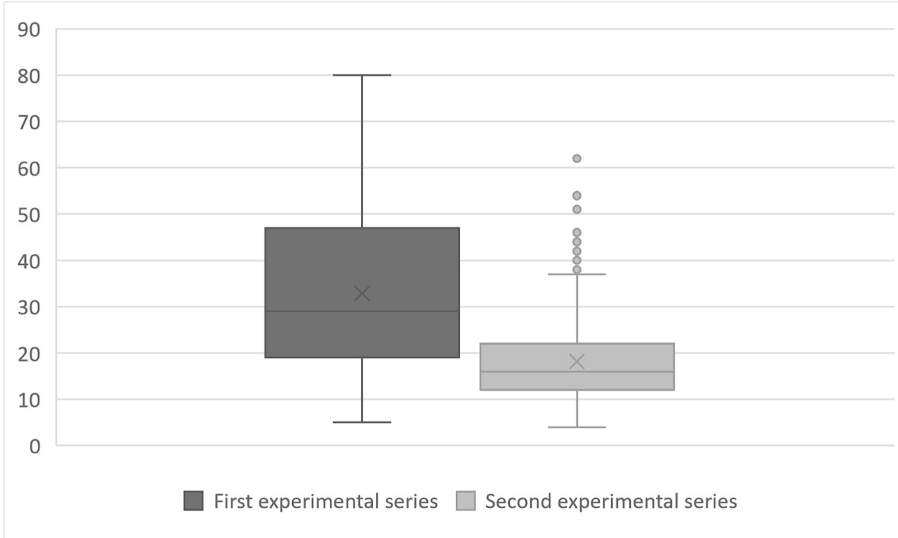

Fig. 5. Length differences (in mm) for flat and articular bones of first and second experimental series.

Table 7
Comparison between the number of bone fragments exposed to the fire and bone fragments recovered after burning.

Anatomical category	Number of bones exposed to the fire	Number of bone fragments recovered from the fire
Total long bones	87	200
Femur	21	34
Humeri	16	39
Tibiae	16	23
Ulnae	15	20
Radii	14	13
Fibulae	5	3
Long bones	0	68
Pelvic girdle	14	28
Cranium*	13	51
Vertebrae	99	110
Ribs	82	117
Scapulae	11	22
Articular bones	16	17
Indeterminate bones	7	493

* Note that the “cranium” category includes mandibular and maxillary bones.

5. Conclusions

The present work contributes to the understanding of small-prey processing, particularly in distinguishing preliminary taphonomic patterns. In terms of cooking, it can be concluded that flesh protects the bone from the heat. Consequently, burning damage is expected to appear only on those parts less covered by meat, and cracking or fragmentation is not commonly observed on these remains. Therefore, identifying the burning pattern of cooking on archaeological bones might be challenging, as they often appear highly fragmented. On the other hand, fresh bones (without flesh) thrown into the embers usually show high burning degrees. Additionally, it is probable to find multiple colourations on the same bone, and cracking and size reduction are also common. To summarize, as proposed by other researchers (e.g., Nicholson, 1993; Lloveras et al., 2009b), the results shown in this work indicate that differential burning of bones depends on the following factors: 1) fire intensity; 2) proximity to the heat source; 3) exposure time; and 4) the amount of meat protecting the bone from the heat. These results are expected to serve as a valuable database that can be applied to archaeological burnt bone assemblages. Conducting further experimental research on small prey bones is particularly important, as burning patterns related to anthropic activities might be interpreted as accidental cremations or post-depositional processes. Therefore, the significance of experimental archaeology for understanding and correctly interpreting archaeological palimpsests should be emphasised.

CRediT authorship contribution statement

Goizane Alonso: Writing – original draft, Methodology, Investigation, Data curation. **Anna Rufà:** Writing – review & editing, Validation. **Ruth Blasco:** Writing – review & editing, Validation, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

This work contributes to the “María de Maeztu” Program for Units of Excellence of the Spanish Ministry of Science and Innovation awarded to the Institut Català de Paleoecologia Humana iEvolució Social (CEX2019-000945-M). R. Blasco and A. Rufà develop their work within the Spanish MICINN project PID2022-138590NB-C41, the Generalitat de Catalunya project CLT009/22/000045 and the PCR « paléoécologie du Lazaret», funded by the Drac Provence-Alpes-Côte d’Azur. R. Blasco is also supported by a Ramon y Cajal research contract by the Spanish Ministry of Science and Innovation (RYC2019-026386-I) and the Generalitat de Catalunya project 2021-SGR-01237. A. Rufà is currently a beneficiary of a CEEC - 3rd Edition research contract promoted by the Portuguese FCT (reference: 2020. 00877.CEECIND), and participates in the Spanish MICIIN projects PID2020-114462GB-I00, and the Generalitat de Catalunya projects CLT009/22/00044 and CLT009/22/00024. We would like to acknowledge the Living Palaeolithic Natural Reserve (Salgüero de Juarros, Castile and Leon, Spain) staff (specially to Eduardo Cerdà and Estefanía Muro) for their dedication and help with the experimental work of this project.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2024.104541.

References

Aldeias, V., Dibble, H.L., Sandgathe, D., Goldberg, P., McPherron, S.J., 2016. How heat alters underlying deposits and implications for archaeological fire features: a controlled experiment. J. Archaeol. Sci. 67, 64–79.

Arilla, M., Rufà, A., Rosell, J., Blasco, R., 2020. Small carnivores' cave-dwelling: neo-taphonomic study of a badger (Meles meles) sett and its archaeological implications. Hist. Biol. 32 (7), 951–965.

Arriaza, M.D.C., Huguet, R., Laplana, C., Pérez-González, A., Márquez, B., Arsuaga, J.L., Baquedano, E., 2017. Lagomorph predation represented in a middle Palaeolithic level of the Navalmaíllo Rock Shelter site (Pinilla del Valle, Spain), as inferred via a new use of classical taphonomic criteria. Quat. Int. 436, 294–306.

Asmussen, B., 2009. Intentional or incidental thermal modification? Analysing site occupation via burned bone. J. Archaeol. Sci. 36 (2), 528–536.

Baena, J., 1997. Arqueología experimental, algo más que un juego. Bol. Arqueol. Exp. 1.

Bellomo, R.V., 1993. A methodological approach for identifying archaeological evidence of fire resulting from human activities. J. Archaeol. Sci. 20 (5), 525–553.

Bellomo, R.V., 1994. Methods of determining early hominid behavioral activities associated with the controlled use of fire at FxJj 20 Main, Koobi Fora, Kenva. J. Human Evol. 27 (1–3), 173–195.

Bennett, J.L., 1999. Thermal alteration of buried bone. J. Archaeol. Sci. 26 (1), 1–8.

Blasco, R., 2008. Human consumption of tortoises at level IV of Bolomor Cave (Valencia, Spain). J. Archaeol. Sci. 35 (10), 2839–2848.

Blasco, R., Fernández Peris, J., 2012a. A uniquely broad-spectrum diet during the Middle Pleistocene at Bolomor Cave (Valencia, Spain). Quat. Int. 252, 16–31.

Blasco, R., Fernández-Peris, J., 2009. Middle Pleistocene bird consumption at level XI of Bolomor cave (Valencia, Spain). J. Archaeol. Sci. 36 (10), 2213–2223.

Blasco, R., Fernández-Peris, J., 2012b. Small and large game: human use of diverse faunal resources at Level IV of Bolomor Cave (Valencia, Spain). C.R. Palevol 11 (4), 265–282.

Blasco, R., Blain, H.A., Rosell, J., Díez, J.C., Huguet, R., Rodríguez, J., Arsuaga, J.L., Bermúdez de Castro, J.M., Carbonell, E., 2011. Earliest evidence for human consumption of tortoises in the European Early Pleistocene from Sima del Elefante, Sierra de Atapuerca, Spain. J. Hum. Evol. 61 (4), 503–509.

Blasco, R., Rosell, J., Peris, J.F., Arsuaga, J.L., de Castro, J.M.B., Carbonell, E., 2013. Environmental availability, behavioural diversity and diet: a zooarchaeological approach from the TD10-1 sublevel of Gran Dolina (Sierra de Atapuerca, Burgos, Spain) and Bolomor Cave (Valencia, Spain). Quat. Sci. Rev. 70, 124–144.

Blasco, R., Rosell, J., Rufà, A., Marco, A.S., Finlayson, C., 2016. Pigeons and choughs, a usual resource for the Neanderthals in Gibraltar. Quat. Int. 421, 62–77.

Blasco, R., Arilla, M., Domínguez-Rodrigo, M., Andrés, M., Ramírez-Pedraza, I., Rufà, R., Rivals, F., Rosell, J., 2020. Who peeled the bones? An actualistic and taphonomic study of axial elements from the Toll Cave Level 4, Barcelona, Spain. Quat. Sci. Rev. 250, 106661.

Blasco, R., Cochard, D., Colonese, A.C., Laroulandie, V., Meier, J., Morin, E., Thompson, J.C., 2022. Small animal use by Neanderthals. In: Updating Neanderthals. Academic Press, pp. 123–143.

Bocherens, H., 2009. Neanderthal dietary habits: review of the isotopic evidence. In: The Evolution of Hominin Diets: Integrating Approaches to the Study of Palaeolithic Subsistence, pp. 241–250.

Brown, K., Fa, D.A., Finlayson, G., Finlayson, C., 2011. Small game and marine resource exploitation by Neanderthals: the evidence from Gibraltar. In: Trekking the Shore: Changing Coastlines and the Antiquity of Coastal Settlement, pp. 47–272.

Buenger, B.A., 2003. The Impact of Wildland and Prescribed Fire on Archaeological Resources. University of Kansas.

Buikstra, J.E., Swegle, M., 1989. Bone modification due to burning: experimental evidence. Bone Modif. 247–258.

Cain, C.R., 2005. Using burned animal bone to look at Middle Stone Age occupation and behavior. J. Archaeol. Sci. 32 (6), 873–884.

Carvalho, M., Pereira, T., Manso, C., 2018. Rabbit exploitation in the Middle Paleolithic at Gruta Nova da Columbeira, Portugal. J. Archaeol. Sci. Rep. 21, 821–832.

Clements, C.B., 2010. Thermodynamic structure of a grass fire plume. Int. J. Wildland Fire 19 (7), 895–902.

Cochard, D., 2004a. Les léporidés dans la subsistancepaléolithique du Sud de la France (Doctoral dissertation). Université Sciences et Technologies-Bordeaux I.

Cochard, D., 2004b. Influence de l'âge des proies sur les caractéristiques des accumulations de léporidésproduites par le hibougrand-duc. In: Petits Animaux Et Sociétés Humaines. Du Complément Alimentaire Aux Ressources Utilitaires. Xxive Rencontres Internationales D'archéologie Et D'histoire D'antibes, pp. 313–316.

Cochard, D., Brugal, J.P., 2004. Importance des fonctions de sites dans les accumulations paléolithiques de léporidés. In: Petits Animaux Et Sociétés Humaines. Du Complément Alimentaire Aux Ressources Utilitaires, pp. 283–295.

Cochard, D., Brugal, J.P., Morin, E., Meignen, L., 2012. Evidence of small fast game exploitation in the Middle Paleolithic of Les Canalettes Aveyron, France. Quat. Int. 264, 32–51.

Coles, J.M., 1979. Experimental Archaeology. Academic Press.

Costamagno, S., Théry-Parisot, I., Castel, J.C., Brugal, J.P., 2009. Combustible ou non? Analyse multifactorielle et modèles explicatifs sur des ossements brûlés paléolithiques. Gestion des combustibles au paléolithique et au mésolithique nouveaux outils, nouvelles interprétations fuel management during the palaeolithic and mesolithic period, 61.

Costamagno, S., Thery-Parisot, I., Brugal, J.P., Guibert, R., 2005. Taphonomic consequences of the use of bones as fuel. Experimental data and archaeological applications. In: Biosphere to Lithosphere: New Studies in Vertebrate Taphonomy, pp. 51–62.

David, B., 1990. How was this bone burnt? In: Solomon, S., Davidson, I., Watson, D. (Eds.), Problem Solving in Taphonomy: Archaeological and Paleontological Studies from Europe, Africa and Oceania, S. Tempus, vol. 2, pp. 63–79.

De Cupere, B., Thys, S., Van Neer, W., Ervynck, A., Corremans, M., Waelkens, M., 2009. Eagle owl (Bubo bubo) pellets from Roman Sagalassos (SW Turkey): distinguishing the prey remains from nest and roost sites. Int. J. Osteoarchaeol. 19 (1), 1–22.

Delaney-Rivera, C., Plummer, T.W., Hodgson, J.A., Forrest, F., Hertel, F., Oliver, J.S., 2009. Pits and pitfalls: taxonomic variability and patterning in tooth mark dimensions. J. Archaeol. Sci. 36 (11), 2597–2608.

Ellingham, S.T., Thompson, T.J., Islam, M., Taylor, G., 2015. Estimating temperature exposure of burnt bone—A methodological review. Sci. Justice 55 (3), 181–188.

Ellingham, S.T., Thompson, T.J., Islam, M., 2016. The effect of soft tissue on temperature estimation from burnt bone using Fourier transform infrared spectroscopy. J. Forensic Sci. 61 (1), 153–159.

Fernández Peris, J., González, V.B., Blasco, R., Cuartero, F., Fluck, H., Sañudo, P., Verdasco, C., 2012. The earliest evidence of hearths in Southern Europe: the case of Bolomor Cave (Valencia, Spain). Quat. Int. 247, 267–277.

Gallo, G., Fyhrie, M., Paine, C., Ushakov, S.V., Izuho, M., Gunchinsuren, B., Navrotsky, A., 2021. Characterization of structural changes in modern and archaeological burnt bone: implications for differential preservation bias. PLoS One 16 (7), e0254529.

Gallo, G., Ushakov, S.V., Navrotsky, A., Stahlschmidt, M.C., 2023. Impact of prolonged heating on the color and crystallinity of bone. Archaeol. Anthropol. Sci. 15 (9), 143.

Gifford-Gonzalez, D., 1989. Ethnographic analogues for interpreting modified bones: some cases from East Africa. Bone Modif. 179–246.

González-Sampériz, P., Leroy, S.A., Carrión, J.S., Fernández, S., García-Antón, M., Gil-García, M.J., Figueiral, I., 2010. Steppes, savannahs, forests and phytodiversity reservoirs during the Pleistocene in the Iberian Peninsula. Rev. Palaeobot. Palynol. 162 (3), 427–457.

Gowlett, J.A., 2006. The early settlement of northern Europe: fire history in the context of climate change and the social brain. C.R. Palevol 5 (1–2), 299–310.

Gowlett, J.A.J., Brink, J.S., Caris, A., Hoare, S., Rucina, S.M., 2017. Evidence of burning from bushfires in southern and east Africa and its relevance to hominin evolution. Curr. Anthropol. 58 (S16), S206–S216.

Gowlett, J.A., Wrangham, R.W., 2013. Earliest fire in Africa: towards the convergence of archaeological evidence and the cooking hypothesis. Azania: Archaeol. Res. Africa 48 (1), 5–30.

Hanson, M., Cain, C.R., 2007. Examining histology to identify burned bone. J. Archaeol. Sci. 34 (11), 1902–1913.

Hardy, B.L., Moncel, M.H., 2011. Neanderthal use of fish, mammals, birds, starchy plants and wood 125–250,000 years ago. PLoS One 6 (8), e23768.

Hardy, B.L., Moncel, M.H., Daujeard, C., Fernandes, P., Béarez, P., Desclaux, E., Gallotti, R., 2013. Impossible Neanderthals? Making string, throwing projectiles and catching small game during Marine Isotope Stage 4 (Abri du Maras, France). Quat. Sci. Rev. 82, 23–40.

Henshilwood, C.S., 1997. Identifying the collector: evidence for human processing of the Cape dune mole-rat, Bathyergus suillus, from Blombos Cave, southern Cape, South Africa. J. Archaeol. Sci. 24 (7), 659–662.

Hockett, B.S., 1996. Corroded, thinned and polished bones created by golden eagles (Aquila chrysaetos): taphonomic implications for archaeological interpretations. J. Archaeol. Sci. 23 (4), 587–591.

Hockett, B.S., Bicho, N.F., 2000. The rabbits of Picareiro Cave: small mammal hunting during the Late Upper Palaeolithic in the Portuguese Estremadura. J. Archaeol. Sci. 27 (8), 715–723.

Hockett, B., Haws, J.A., 2002. Taphonomic and methodological perspectives of leporid hunting during the Upper Paleolithic of the Western Mediterranean Basin. J. Archaeol. Method Theory 9, 269–302.

Ingersoll, D., Yellen, J.E., MacDonald, W. (Eds.), 1977. Experimental Archaeology. Columbia University Press, New York.

Johnson, E., 1989. Human modified bones from early southern Plains Sites. Bone Modif. 431–471.

Kiszely, I., 1973. Derivatographic examination of subfossil and fossil bones. Curr. Anthropol. 14 (3), 280–286.

Knight, J.A., 1985. Differential preservation of calcined bone at the Hirundo Site, Alton, Maine. Master's Thesis in Quaternary Studies, University of Maine, Orono.

Krajcarz, M., Krajcarz, M.T., 2014. The red fox (Vulpes vulpes) as an accumulator of bones in cave-like environments. Int. J. Osteoarchaeol. 24 (4), 459–475.

Landt, M.J., 2007. Tooth marks and human consumption: ethnoarchaeological mastication research among foragers of the Central African Republic. J. Archaeol. Sci. 34 (10), 1629–1640.

Laroulandie, V., Faivre, J.P., Gerbe, M., Mourre, V., 2016. Who brought the bird remains to the Middle Palaeolithic site of Les Fieux (Southwestern, France)? Direct evidence of a complex taphonomic story. Quat. Int. 421, 116–133.

Laroulandie, V., 2005. Bird exploitation pattern: the case of Ptarmigan Lagopus sp. in the Upper Magdalenian site of La Vache (Ariège, France). In: Grupe, G., Peters, J. (Eds.), Feathers, grit and symbolism. Birds and humans in the ancient Old and New Worlds. Proceedings of the 5th Meeting of the ICAZ Bird Working Group, Munich, 26-28 July 2004. (Documenta Archaeobiologiae 3). Verlag Marie Leidorf, pp. 165–178.

Lloveras, L., Moreno-Garcia, M., Nadal, J., 2008. Taphonomic analysis of leporid remains obtained from modern Iberian lynx (Lynx pardinus) scats. J. Archaeol. Sci. 35 (1), 1–13.
Lloveras, L., Moreno-García, M., Nadal, J., 2009a. The eagle owl (Bubo bubo) as a leporid remains accumulator: taphonomic analysis of modern rabbit remains recovered from nests of this predator. Int. J. Osteoarchaeol. 19 (5), 573–592.
Lloveras, L., Moreno García, M., Nadal, J., 2009b. Butchery, cooking and human consumption marks on rabbit (Oryctolagus cuniculus) bones: an experimental study. J. Taphonomy 7 (2–3), 179–201.
Lloveras, L., Moreno-García, M., Nadal, J., Zilhão, J., 2011. Who brought in the rabbits? Taphonomical analysis of Mousterian and Solutrean leporid accumulations from Gruta do Caldeirão (Tomar, Portugal). J. Archaeol. Sci. 38 (9), 2434–2449.
Lloveras, L., Moreno-García, M., Nadal, J., 2012. Assessing the variability in taphonomic studies of modern leporid remains from Eagle Owl (Bubo bubo) nest assemblages: the importance of age of prey. J. Archaeol. Sci. 39 (12), 3754–3764.
Lloveras, L., Thomas, R., Lourenço, R., Caro, J., Dias, A., 2014. Understanding the taphonomic signature of Bonelli's Eagle (Aquila fasciata). J. Archaeol. Sci. 49, 455–471.
Lloveras, L., Cosso, A., Solé, J., Claramunt-López, B., Nadal, J., 2018a. Taphonomic signature of golden eagles (Aquila chrysaetos) on bone prey remains. Hist. Biol. 30 (6), 835–854.
Lloveras, L., Thomas, R., Cosso, A., Pinyol, C., Nadal, J., 2018b. When wildcats feed on rabbits: an experimental study to understand the taphonomic signature of European wildcats (Felis silvestris silvestris). Archaeol. Anthropol. Sci. 10, 449–464.
Lyman, R.L., 1994. Vertebrate Taphonomy. Cambridge University Press.
Mallye, J.B., Cochard, D., Laroulandie, V., 2008, July. Accumulations osseuses en périphérie de terriers de petits carnivores: les stigmates de prédation et de fréquentation. In: Annales de Paléontologie, vol. 94, No. 3. Elsevier Masson, pp. 187–208.
Marquer, L., Otto, T., Nespoulet, R., Chiotti, L., 2010. A new approach to study the fuel used in hearths by hunter-gatherers at the Upper Palaeolithic site of Abri Pataud (Dordogne, France). J. Archaeol. Sci. 37 (11), 2735–2746.
Mathieu, J.R., 2002. Experimental archaeology. BAR Int. Ser. 1035.
Medina, M.E., Teta, P., 2012. Burning damage and small-mammal human consumption in Quebrada del Real 1 (Cordoba, Argentina): an experimental approach. J. Archaeol. Sci. 39 (3), 737–743.
Mentzer, S.M., 2009. Bone as a fuel source: the effects of initial fragment size distribution. In: Fuel managment during the Palaeolithic and Mesolithic period. New tools, new interpretations. Proceedings of the XVth World congress (Lisbon, 4-9 september 2006), Oxford, Archaeopress («BAR International Series» 1914), pp. 49–60.
Morin, E., Maier, J., El Guennouni, K., Moigne, A.M., Lebreton, L., Rusch, L., Cochard, D., 2019. New evidence of broader diets for archaic Homo populations in the northwestern Mediterranean. Sci. Adv. 5 (3), eaav9106.
Nabais, M.V.B.D.C., 2021. Neanderthal Diets in Portugal: Small and Large Prey Consumption during the Marine Isotope Stage 5 (MIS-5). UCL (University College London). Doctoral dissertation.
Nabais, M., Zilhão, J., 2019. The consumption of tortoise among last interglacial Iberian Neanderthals. Quat. Sci. Rev. 217, 225–246.
Nicholson, R.A., 1993. A morphological investigation of burnt animal bone and an evaluation of its utility in archaeology. J. Archaeol. Sci. 20 (4), 411–428.
Outram, A.K., 2008. Introduction to experimental archaeology. World Archaeol. 40 (1), 1–6.
Pelletier, M., Desclaux, E., Brugal, J.P., Texier, P.J., 2019. The exploitation of rabbits for food and pelts by last interglacial Neandertals. Quat. Sci. Rev. 224, 105972.
Peresani, M., Fiore, I., Gala, M., Romandini, M., Tagliacozzo, A., 2011. Late Neandertals and the intentional removal of feathers as evidenced from bird bone taphonomy at Fumane Cave 44 ky BP, Italy. Proc. Natl. Acad. Sci. 108 (10), 3888–3893.
Pérez, L., Sanchis, A., Hernández, C.M., Galván, B., Sala, R., Mallol, C., 2017. Hearths and bones: an experimental study to explore temporality in archaeological contexts based on taphonomical changes in burnt bones. J. Archaeol. Sci. Rep. 11, 287–309.
Real, C., 2020. Rabbit: more than the Magdalenian main dish in the Iberian Mediterranean region. New data from Cova de les Cendres (Alicante, Spain). J. Archaeol. Sci. Rep. 32, 102388.
Reidsma, F.H., van Hoesel, A., van Os, B.J., Megens, L., Braadbaart, F., 2016. Charred bone: physical and chemical changes during laboratory simulated heating under reducing conditions and its relevance for the study of fire use in archaeology. J. Archaeol. Sci. Rep. 10, 282–292.
Rodríguez-Hidalgo, A., Lloveras, L., Moreno-García, M., Saladié, P., Canals, A., Nadal, J., 2013b. Feeding behaviour and taphonomic characterization of non-ingested rabbit remains produced by the Iberian lynx (Lynx pardinus). J. Archaeol. Sci. 40 (7), 3031–3045.
Rodríguez-Hidalgo, A.J., Saladié, P., Canals, A., 2013a. Following the white rabbit: a case of a small game procurement site in the Upper Palaeolithic (Sala de las Chimeneas, Maltravieso cave, Spain). Int. J. Osteoarchaeol. 23 (1), 34–54.
Rodríguez-Hidalgo, A., Saladié, P., Marín, J., Canals, A., 2015. Expansion of the referential framework for the rabbit fossil accumulations generated by Iberian lynx. Palaeogeogr. Palaeoclimatol. Palaeoecol. 418, 1–11.
Rosado-Méndez, N.Y., Lloveras, L., García-Argüelles, P., Nadal, J., 2019. The role of small prey in hunter–gatherer subsistence strategies from the Late Pleistocene-Early Holocene transition site in NE Iberia: the leporid accumulation from the Epipalaeolithic level of Balma del Gai site. Archaeol. Anthropol. Sci. 11, 2507–2525.
Rufà, A., Blasco, R., Rivals, F., Rosell, J., 2014. Leporids as a potential resource for predators (hominins, mammalian carnivores, raptors): an example of mixed contribution from level III of Teixoneres Cave (MIS 3, Barcelona, Spain). C.R. Palevol 13 (8), 665–680.
Saladié, P., Rodríguez-Hidalgo, A., Díez, C., Martín-Rodríguez, P., Carbonell, E., 2013. Range of bone modifications by human chewing. J. Archaeol. Sci. 40 (1), 380–397.
Sanchis, A., 2000. Los restos de Oryctolagus cuniculus en las tafocenosis de Bubo bubo y Vulpes vulpes y su aplicación a la caracterización del registro faunístico arqueológico. Saguntum 32, 31–50.
Sanchis, A., 2010. Los lagomorfos del Paleolítico medio de la región central y sudoriental del mediterráneo ibérico: caracterización tafonómica y taxonómica. Universitat de València). Doctoral dissertation.
Sanchis, A., Morales, J.V., Pérez Ripoll, M., 2011. Creación de un referente experimental para el estudio de las alteraciones causadas por dientes humanos sobre huesos de conejo. In: Morgado, A., Baena, J., García, D. (Eds.), Actas del Segundo Congreso Internacional de Arqueología experimental, Ronda, Málaga. Noviembre 2008. Granada, Universidad de Granada, pp. 343–349.
Sanchis, A., Fernández-Peris, J., 2008. Procesado y consumo antrópico de conejo en la Cova del Bolomor (Tavernes de la Valldigna, Valencia). El nivel XVIIc (ca 350 ka)/ Anthropic processing and consumption of rabbit at the Bolomor Cave (Tavernes de la Valldigna, Valencia). The XVIIc level (ca 350 ka). Complutum 19 (1), 25.
Sanchis, A., Pascual Benito, J.L., 2011. Análisis de las acumulaciones óseas de una guarida de pequeños mamíferos carnívoros (Sitjar Baix, Onda, Castellón): implicaciones arqueológicas. Archaeofauna 20 (1).
Sanchis, A., Morales, J.V., Pérez, L., Hernández, C.M., Galván, B., 2015. La tortuga mediterránea en yacimientos valencianos del Paleolítico medio: distribución, origen de las acumulaciones y nuevos datos procedentes del Abric del Pastor (Alcoi, Alacant). Preses Petites i Grups Humans En El Passat 97–120.
Sanchis, A., Real, C., Pérez Ripoll, M., Villaverde, V., 2016. El conejo en la subsistencia humana del Paleolítico superior inicial en la zona central del Mediterráneo Ibérico. In: Lloveras, L., Rissech, C., Nadal, J., Fullola, J.M. (Eds.), What Bones Tell Us/el Que Ens Expliquen Els Ossos. Monografies Del SERP. Universitat de Barcelona, pp. 145–156.
Schmitt, D.N., 1995. The taphonomy of Golden Eagle prey accumulations at Great Basin roosts. J. Ethnobiol. 15, 237–256.
Shipman, P., Foster, G., Schoeninger, M., 1984. Burnt bones and teeth: an experimental study of color, morphology, crystal structure and shrinkage. J. Archaeol. Sci. 11 (4), 307–325.
Slimak, L., Lewis, J.E., Crégut-Bonnoure, E., Metz, L., Ollivier, V., André, P., Magnin, F., 2010. Le Grand Abri aux Puces, a Mousterian site from the Last Interglacial: paleogeography, paleoenvironment, and new excavation results. J. Archaeol. Sci. 37 (11), 2747–2761.
Spennemann, D.H., Colley, S.M., 1989. Fire in a pit: the effects of burning on faunal remains. Archaeozoologia 3 (1–2), 51–64.
Speth, J.D., Tchernov, E., 2002. Middle Paleolithic tortoise use at Kebara cave (Israel). J. Archaeol. Sci. 29 (5), 471–483.
Stiner, M.C., Kuhn, S.L., Weiner, S., Bar-Yosef, O., 1995. Differential burning, recrystallization, and fragmentation of archaeological bone. J. Archaeol. Sci. 22 (2), 223–237.
Téllez, E., Saladié, P., Pineda, A., Marín, J., Vallverdú, J., Chacón, M.G., Carbonell, E., 2022. Incidental burning on bones by Neanderthals: the role of fire in the Qa level of AbricRomaní rock-shelter (Spain). Archaeol. Anthropol. Sci. 14 (6), 119.
Théry-Parisot, I., 2002. Fuel management (bone and wood) during the Lower Aurignacian in the Pataud rock shelter (Lower Palaeolithic, Les Eyzies de Tayac, Dordogne, France). Contribution of experimentation. J. Archaeol. Sci. 29 (12), 1415–1421.
Théry-Parisot, I., Costamagno, S., Brugal, J.P., Castel, J.C., Gerbe, M., Bouby, L., Guilbert, R., 2009. La question des os brûlésdans les sites du Paléolithique. Un programmed'archéologieexpérimentale en taphonomie. Les Nouvelles De L'archéologie 118, 31–36.
Thompson, T., 2004. Recent advances in the study of burned bone and their implications for forensic anthropology. Forensic Sci. Int. 146, S203–S205.
Thompson, T.J., 2015. The analysis of heat-induced crystallinity change in bone. In: The Analysis of Burned Human Remains. Academic Press, pp. 323–337.
Ugan, A., 2008. The effect of cooking on the survivorship of jackrabbit skeletons (Lepus californicus) presented to desert scavengers of the Eastern Great Basin, North America. Int. J. Osteoarchaeol. 20 (2), 214–226.
van Hoesel, A., Reidsma, F.H., van Os, B.J., Megens, L., Braadbaart, F., 2019. Combusted bone: physical and chemical changes of bone during laboratory simulated heating under oxidising conditions and their relevance for the study of ancient fire use. J. Archaeol. Sci. Rep. 28, 102033.
Vidal-Matutano, P., Blasco, R., Sañudo, P., Fernández Peris, J., 2019. The anthropogenic use of firewood during the European Middle Pleistocene: charcoal evidence from levels XIII and XI of Bolomor Cave, Eastern Iberia (230–160 ka). Environ. Archaeol. 24 (3), 269–284.
Yravedra, J., Uzquiano, P., 2013. Burnt bone assemblages from El Esquilleu cave (Cantabria, Northern Spain): deliberate use for fuel or systematic disposal of organic waste? Quat. Sci. Rev. 68, 175–190.
Yravedra, J., Álvarez-Alonso, D., Estaca-Gómez, V., López-Cisneros, P., Arrizabalaga, Á., Elorza, M., Uzquiano, P., 2017. New evidence of bones used as fuel in the Gravettian level at Coímbre cave, northern Iberian Peninsula. Archaeol. Anthropol. Sci. 9, 1153–1168.